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AMERICAN AVIATION TODAY AS A DECISIVE FACTOR IN WORLD AFFAIRS.*

BY

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United States civil aviation has reached the highest known pinnacles of world supremacy and is now on trial for its life! It long has been termed a "backlog of national defense," and now the hour of proof has arrived. Our citizens and their Government will judge whether the national interest may require that civil aviation as such be relegated to temporary or permanent oblivion, subjected to partial eclipse, or developed further as a vital part of national and hemisphere defense and a decisive factor in world affairs.

It is my fortunate privilege to present to The Franklin Institute a review of the past development of aviation, a study of current trends, and some suggestions as to its future. We are half-way through the first month of 1941, and the balance of this year may well determine whether human happiness and liberty, Government by and for the people, and civilization as we have known it can survive. The final determination depends very largely upon the dynamic forces of aviation.

Philadelphia, where the independence of our country was declared, is a particularly appropriate place to state the case of American civil aviation which can play a vital part in

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maintaining that independence. Benjamin Franklin helped to establish and then valiantly defend our independence, and clearly foresaw one manner in which it might be lost. There is more significance today than ever before in his words to a friend, when, referring to aviation, he said, "It appears, as you observe, to be a discovery of great importance and what may possibly give a new turn to human affairs. Convincing sovereigns of the folly of war may perhaps be one effect of it, since it will be impossible for the most potent of them to guard his dominions. . . . And where is the Prince who can afford so to cover his country with troops for its defense as that thousands of men descending from the clouds might not do an indefinite deal of mischief before a force could be brought together to repel them." The terrible truth of Benjamin Franklin's prophecy at last is being realized.

Germany has invested many years of great aeronautical progress in the present carefully coördinated employment of all airplanes as instruments of aggression and as a means of waging a new form of total warfare—a warfare which recognizes no battle lines, but rather includes vast areas of land and water and blasts entire populations with its fury. Civilians now are realizing that their own activities in the face of danger are as important as the activities of their regular military forces. There is no clear division between civil and military power in attempting to weigh the chances of victory, defeat, or even survival. It no longer is true that only some of the people "go off to war"—Today, the war comes to all of the people!

Since aviation has revolutionized the nature and extent of aggression and warfare, it is vital that we take stock of our own aeronautical resources. Other nations in varying degrees have controlled their aviation activities as governmental or military projects, whereas our policy in the United States has been one of encouragement to private enterprise in the development of our civil aviation industry. As a result, we find among our outstanding national assets today the greatest quantity and the highest quality of civil aviation in the world, and we should appraise its current worth and future value honestly and frankly.

In order to understand the present situation, it is helpful

to take a brief glance over our shoulder at the history of aviation up to about three years ago and to make a more detailed study of it thereafter. It always is helpful to my own thinking to realize that the airplane and I are the same age, since we came into being within two weeks of each other. Neither of us are so very old and neither of us grew to much stature until after our tenth year, or thereabouts! In those first ten years after the Wright Brothers flight at Kitty Hawk in 1903, there were certain outstanding milestones—the first officially recorded flight which was made by Orville Wright at Dayton in 1905; Bleriot's flight across the English Channel in 1909, the same month in which the United States War Department acquired the first military airplane in the world; Glen Curtis's non-stop Albany to New York flight in 1910; and Hoxsie's famous altitude record of 11,474 feet the same year. These and similar events recorded the slow improvement until the military value of the airplane gradually became apparent during the first World War.

According to a United States Army pamphlet entitled, "Aircraft Production Facts," published in 1919, it is probable that Germany entered the last war with nearly 1,000 airplanes; France, with about 300; and England with about 250—whereas, the air forces of the United States' Army included only five trained officers and a minimum of equipment. Even by 1917, when we entered the war, only a meager total of 142 airplanes had been delivered to the United States' Signal Corps, and most of those were already obsolete or destroyed. Not a single one of our airplanes was suitable for use on the battlefront. In 1917, the United States had practically no material, personnel or experience in the design, production or use of aeronautical equipment, no accurate knowledge of the aeronautical requirements of warfare, and no adequate aircraft manufacturing facilities.

Quoting directly from this same Army pamphlet of 1919, "It is interesting to consider that almost identical forms of the fireworks we burn on the fourth of July and similar celebrations are utilized for aerial warfare. The principal use to which pyrotechnics is put is that of signalling from the airplane to the ground and vice versa, also from one plane to others in the air at the same time. . . . Until almost a year

after the war began, 'airplanes' were armed with various weapons, such as service rifles, automatic rifles, automatic pistols, shotguns shooting large shot held together by wire, and also equipped with grenades and darts, which were intended to drop on their adversaries. Needless to say, the damage done by those weapons was slight, owing to the great difficulty of one moving object hitting another. There are many stories of frightening the Hun with Very pistols, which shot Roman candle balls!"

I now come to a quotation which is particularly interesting for the sake of comparing the military value of aircraft during the first World War with the multitudinous functions which aviation performs in the current conflict—"Contrary to general belief outside of military circles, the principal function of the airplanes is the securing of information, and the camera secures and retains this information with fatal accuracy." And that apparently summarizes the conclusions of the United States Army in 1919 as to the military value of the airplane!

In the years immediately following the first World War, national policies were established and patterns set which can be traced through to the present European aerial holocaust.

In Europe, Germany found herself deprived of all her military aircraft and restricted by the Versailles treaty from establishing any admitted military air force. Consequently, German ingenuity and initiative were directed toward the establishment of airlines, toward gliding as a means of saving gasoline while training pilots, and, with ever increasing emphasis, toward fundamental research in order to obtain maximum use from available materials while increasing the efficiency of their airplanes. The military value of these activities was realized, and, when political conditions in Europe permitted, they were used first secretly, and then openly, to form the nucleus of the present German air force. France and England, finding themselves with surplus military equipment and pilots, began laying the foundation of their network of airline operations. Other European countries followed in competition on the airways.

As early as August, 1919, passengers were being carried on regular air services between London and Paris and that same year French airlines operated as far east as Warsaw and

south to Casa Blanca in French Morocco. It was also in the year 1919 that Dr. Peter Paul Von Bauer founded the German airline in Colombia known as Scadta, which soon became the first successful commercial aviation enterprise in the world. Between the armistice and 1920, one German airline flew 625,000 miles and carried 5,500 passengers and 500 tons of freight. Never forgetting the military potentialities of the airplane, most of the European governments financed and controlled their airlines, which were greatly expanded while disguised as private companies. The philosophy of the "freedom of the air" was abandoned in favor of international reciprocal operating rights at the Paris Convention of 1919. This established national sovereignty of the airspace for the strict supervision and control of foreign aircraft and added a well nigh crushing burden of complication on the development of private flying in Europe. All pilot training was undertaken almost universally with government subsidies and under government supervision.

In the United States, we have a right to be proud of the first permanent, scheduled air mail service in the world, which the United States Government inaugurated between New York and Washington on May 15, 1918. But that service, impressive as it certainly was, was limited. Even with the addition of the Government's experimental two and a half-day air mail route between New York and San Francisco on September 8, 1920, our own airline accomplishments lagged far behind other countries during a considerable portion of aviation history. In 1926, under the Kelly Act, which took the Government out of the airline business, air mail contracts were let for the first time to private operators. This was an important milestone and should be remembered for the practice of free enterprise in civil aviation has continued ever since as a matter of basic national policy.

Our returning war pilots found little to occupy their energy except barnstorming. The spirit of American adventure found expression in the establishment of new records and spectacular long distance flights. The solo hop of Charles Lindbergh from New York to Paris in 1927 was followed by a great wave of public enthusiasm for aviation at a time when our country was luxuriating in prosperity and eager to sup-

port new enterprises. That same year marked the inauguration of our first regularly operated international airline between Florida and Cuba by Pan American Airways.

The National Advisory Committee for Aeronautics was founded in 1915 as the Federal Agency to undertake and coördinate fundamental research in aeronautics. The N. A. C. A. rapidly reached a position of world leadership in its field, a leadership which was maintained until a few years ago and now is well on its way toward re-establishment, as I shall mention later.

I need not dwell long on the unpleasant events of the early 1930's in our country, which were the results of the over-expansion and over-enthusiasm of the late 1920's. We all remember pages of our aviation history darkened by collapsed financial structures, dissolution of involved corporate relationships, reversion of airport projects to swamp lands, empty factories, and unemployed aircraftsmen. I must emphasize, however, the glowing fact that sicentific research and aeronautical engineering continued to progress. Airline traffic increased steadily and it was actually during this period that our domestic and international airlines forged ahead to world leadership. However, the various financial difficulties of the domestic airlines were too great, and, by 1938 most of them were in a chaotic financial condition and many of them could not have continued operation much longer.

The year 1938 marked the end of the period following the last World War and opened a new era for aviation and, consequently, for many of the world's affairs.

In September, 1938, I was acting as Chairman of the American Delegation to the Fourth International Conference on Private Air Law in Brussels—a conference concerned most peacefully and dryly with the drafting of certain legal codes for the operation of aircraft—when it looked as though we would be caught in the center of a vicious European war with Mars, not Law, piloting aviation. War at that time was avoided largely because Prime Minister Chamberlain made some round trips between London and Munich in an American Lockheed airplane operated by the British Airways, Limited.

After the Munich agreement, I made a survey of European civil aviation on behalf of our government, visiting seven

countries, including Italy and Germany. Like so many other aviation people who had recently visited Germany, I was greatly impressed by the vast potential power of their aviation and their thorough preparations for future aerial warfare. I was convinced that the policy of the Italian Government could be best expressed in Mussolini's motto, "Aviation is the Army of tomorrow!" Additional confirmation of that policy was found in the fact that Il Duce continued to act as his own Air Minister.

In Germany, General Goering, the Number Two Nazi, who maintained his most important Government post as Chief of Aviation, stated after Munich, "Let us not deceive ourselves. . . . The German air force is the terror of our opponents and will remain so."

While the European aggressors were using aviation primarily as a threat against the peace of the world, in that same year of 1938 probably the greatest aviation event in the United States was the passage of the Civil Aeronautics Act. This may not seem like much of an event, but, judging by its results, we find it was an important part of the answer to that threat from abroad. This Act concentrated responsibility for the "encouragement and development of civil aeronautics" in one agency, whereas, previously, it had been divided among various departments, agencies and committees for whom the solution of the problems of aviation was only a comparatively minor function. In no less than 38 places, the Act mentions the needs of national defense as one of the controlling elements of public interest in guiding the development of civil aviation.

Now, let us look at this lively item in the arsenal of the democracies! One of the outstanding achievements of the United States has been the creation and operation of a vast network of civil airways with their efficiently coördinated revolving beacons, radio ranges, teletype circuits, traffic control centers, and related facilities, all of which are designed to control and guide the flight of aircraft in the interests of safety. The tremendous expansion of aviation activities and the resultant possibilities of traffic congestion in the air have made it necessary to extend these civil airways and improve them as rapidly as possible to meet the added demands. As a

result, the mileage of fully equipped civil airways has been increased 40 per cent. in the last three years.

Nowhere else in the world have aids to aerial navigation been developed to even a fraction of the extent which holds true in our country. On European airways there have been only a few scattered facilities.

The public has been under the impression that our civil airways of the United States were created and are still being maintained for the sake of our airline operations. In general, this was true in the past, but it certainly is not true at present. The Signal Corps of the United States Army began experimenting with radio telegraph communications from airplanes to the ground in 1910 and the Government began developing various forms of airway facilities in connection with the transcontinental services which were started in 1920. In the past, extensions of our domestic airlines required a corresponding expansion of airway facilities, but currently I have reason to believe that the airlines are the least users of our airways. It is difficult to obtain exact figures on the subject, but it is probable that airplane miles flown by the airlines over the federal airways during the past twelve months or so have been less than the number flown by other types of civil aircraft, and I am very certain that our military aircraft have been using the airway facilities to an extent far in excess of the airlines. If in time of peace our military forces draw so heavily upon these facilities, in time of war these civil air navigation aids will have an immeasurable value to the Army and Navy for the quick concentration of forces, the transportation of troops, and what is equally important—the continued operation of a civilian air transportation system to provide the rapid communications which will become even more essential in time of grave emergency.

Airports are so vital to all airplanes that any inadequacy of them is a serious restriction upon military effectiveness. We are fortunate in having a considerable number of airports, created in the past and maintained primarily for civil aviation, which now are available for our military forces. That system of airports is being continually enlarged and improved. At the end of 1940, there were about 2,400 airports in the country, of which 69 were Army and 22 were Naval fields.

Although started during the first World War in 1915 primarily for the sake of the development of military aviation, the fundamental research activities of the N. A. C. A. serve all aviation. The contribution to progress which has been made by it, by military aviation, by various of our private airline companies, and by many of our manufacturing companies has been tremendous. In 1938, various representatives of American aviation, including myself, discovered and reported that we had fallen so sadly behind that Germany had perhaps six to eight times the facilities for aeronautical research that we possessed. Since the value of aviation to our country is limited to the efficiency of our aircraft, the influence of American aviation in world affairs rests upon the foundation of research and engineering. Recently, Congress wisely has appropriated sufficient funds for extensive enlargement of our research facilities so that again we may claim world leadership.

In its current annual report, issued January 13th, the N. A. C. A. emphasizes that ways and means should be found to sustain and continue the advance of commerical aeronautics. It states that air mail and passenger transportation, which have already become of great value to the nation, would be essential to our industrial effectiveness in time of war.

Those nations, big and small, which are valiantly resisting the thrusts of the aggressors or are preparing for such resistance, desperately need our airplanes. Our own need for them is great. All our citizens and the entire world wants to know how many airplanes we can produce in our arsenal of the democracies. The freedom-loving part of the world should not feel gloomy for when we look in that arsenal we find that our civil aviation has contributed to the building of a reserve of air power whose potentialities are yet to be realized.

When we entered the first World War with virtually no aircraft production facilities, factories of other industries were drafted to help manufacture airplanes. After the War, much of that suddenly created capacity returned to its original or new uses and those manufacturers who chose to remain as a basic part of the aviation industry went through several years of vicissitudes. As civil aviation increased in scope and im-

portance it bore an ever-increasing share of responsibility for keeping our manufacturers going. Due to the differences in size and cost, it is difficult to find any simple and acceptable standard for measuring aircraft production, especially when comparing military and civil aircraft. Bearing this in mind and using round figures, we find that of all the airplanes produced in the United States for the ten years of 1930 to 1939 military aircraft accounted for a little over half the value but only about one-third of the number. The remainder during those ten years was accounted for by civil aircraft production, for both the domestic and export markets. Civil aviation certainly has been right up in the front-line trenches in keeping a great part of our production capacity alive and progressive for the very sort of emergency which now faces us.

As a reasonably fair gauge of expansion in civil aviation resulting from the opening of the new chapter in 1938, we find that the number of certificated civil aircraft in the United States has increased 72 per cent. to over 17,000 in less than two and one-half years. Comparable figures for military aviation are not publicly available these days, but it is a matter of general knowledge that the production of military aircraft has been increased at truly phenomenal rates. In the single year of 1940, aircraft factories' floor space was increased 87 per cent. while the number of productive workers in aircraft plants has increased 190 per cent. The history of aircraft production is a saga of civilian achievement—the frustrations and successes of civilian research and engineering, the perseverance of labor and capital with the courage of its convictions and a vision of the aeronautical future.

When we entered the war in 1917, the total number of airplanes which had been delivered to the Signal Corps of the Army was a paltry 142. But by the armistice in 1918, we had produced nearly 17,000 planes! By a coincidence this was the number of certificated civil aircraft of our country at the end of last year. Recognizing the urgency of still greater endeavor, how different is the present situation from even the end of the first World War!

The training of aircraft mechanics and skilled laborers has progressed at a rate nearly comparable to the tremendous expansion which has taken place in the rest of the industry

since 1938. Mechanics certificated by the Civil Aeronautics Authority increased from 9,600 to over 11,000 at the end of 1940. Civilian schools throughout the country have been training many additional mechanics for the Army and Navy.

An expert pilot can do amazing things with a poor airplane, but no matter how brilliantly engineered, soundly produced, or carefully maintained, an airplane in the hands of a poor pilot is worse than useless. Recognizing this obvious truth, Germany had trained so many pilots by 1938 that the number of our own was insignificant by comparison. In order to increase the number of our airmen, our Civil Pilot Training Program was started in the spring of 1939. But, in this program, our Government again broke away from the European example of military instruction and control and placed the future welfare of our aviation on a foundation of private enterprise and initiative.

Flight training was not undertaken directly by our Government but through existing flying schools. The basic policy originally laid down for the Civil Pilot Training Program contemplated that it should be justified on educational and economic grounds alone, apart from the great significance which it held in connection with national defense. Any of the young people who have gone through the course can attest to the educational values of it. Economically, it directly benefits the manufacturer of small planes, the struggling instructors, and rebounds to the benefit of air transportation through the increased interest in aviation which would naturally result. Now that we are in a period of frenzied expansion of aircraft plant capacities, I foresee perhaps an even greater economic value in the cushion which will be provided against the slump which will follow the cessation of hostilities with the consequent need to find new markets. The program has already made a great military contribution, for over 2,600 graduates of the course have entered the Army and Navy schools and large numbers of highly trained civil instructors have undertaken the instruction of military student pilots in the United States and in Canada. During 1940, an advanced instructor training course was given to 3,223 trainees, thus creating a reservoir of skilled pilots for any emergency!

On the effective date of the Civil Aeronautics Act of 1938.

there were over 20,000 certificated civilian pilots in the United States. Today there are over 65,000 and an additional 26,000 are receiving training. By the end of this year we should have 100,000 trained civilian pilots.

The best of pilots, flying the best of airplanes, still are subject to the weather. So important has the weather become in European warfare that it is classified as a military secret! The United States Weather Bureau has 7,442 stations scattered throughout our country and ten at various strategic points beyond our borders, all of them coöperating closely to supply the needs of aviation.

Now that our airlines are approaching the maturity of an important transportation industry, we are apt to forget the days prior to 1938 when the many problems of the air transport companies constituted one of the greatest threats to the future of our aviation. Economic difficulties were tremendous. Competitive bidding for airmail contracts, usually under compulsion to obtain an airmail contract or not operate an airline at all, finally degenerated to a point of pure lunacy. Bids as low as a mill a mile, for carrying up to 300 pounds of mail, were tendered, and one bidder who offered to carry the mail for approximately one cent every three months lost the contract to a competitor who bid absolute monetary zero. As a consequence, banks would not loan nor investors buy stock in such uncertain enterprises. All but a very few of the transport companies were facing the threat of bankruptcy. The unanimous plea of every member of the aviation industry and of everyone interested in the future welfare of aeronautics was for a single Federal agency which would encourage and develop civil aeronautics and at the same time regulate its growth in a manner designed to promote economic self-sufficiency. The Civil Aeronautics Act of 1938 was Congress's answer to that plea.

Favorable results came almost immediately. Stability replaced chaos and the air carriers once more became a bankable risk and their stock became a good investment. Just how complete was the reversal in trend can be shown by the earnings record of the transport companies themselves. In the fiscal year ending June 30, 1938, the total deficit of all domestic airmail carriers was $1,500,000. By the end of the

fiscal year 1939, less than one year after the Civil Aeronautics Act became effective, the carriers showed a total net profit of $1,272,000 and profits have shown a healthy increase ever since. This improvement took place in the face of a reduction in the percentage of total revenues represented by mail pay from 36 per cent. in the fiscal year ending June 30, 1938, to 28 per cent. in the period ending June 30, 1940. Revenue passenger miles flown in the first eleven months of 1940 were 58 per cent. over the same period of 1939. The Post Office Department is approximately breaking even on its payments to the domestic air carriers which eliminates that element of tax payer subsidy. And, in spite of three unfortunate accidents last year, the airlines have continued to establish constantly improving records of efficiency and safety.

World events are emphasizing the vital importance of our international airlines. In 1938, they already were crossing the Pacific to China, serving Canada at three points within her southern border, and operating throughout the West Indies, Central, and South America; but, since then, there have been far-flung extensions and great improvements in all directions.

To the west, additional transpacific airline operations were inaugurated last year from San Francisco to New Zealand and application recently has been made to our Civil Aeronautics Board for service to Singapore through an addition to the route to China.

To the east, the regular transatlantic flights of Pan American Airways were started in 1939 to England and France. After those countries entered the war, the President's Neutrality Proclamation and the delineation of combat zones left Portugal as the only available terminal in Europe not only for the existing air carrier, but also the additional operations of American Export Airlines, which were authorized by our Board and approved by the President last year. By the close of 1938, England, France, Italy and Germany had completed various experimental flights across the Atlantic and no less than ten European countries, including those four, had indicated their desire to operate regular commercial airlines to the United States, either in their own name, or, as in the case of the Scandinavian group, as a joint enterprise. The

war has brought recognition of the great necessity for frequent, adequate, and reliable air transportation to and from Europe and the United States now has an opportunity to entrench two American air carriers in the Atlantic service, thus establishing a preeminence in that field which we may hope to maintain indefinitely.

To the north, airline service was authorized and started last year between Seattle and Alaska, thus providing regular connections over the so-called outside route with the extensive and extremely active civil aviation activities within Alaska providing most of the transportation within that territory. Operations also were authorized a few weeks ago between Great Falls and Lethbridge to connect our domestic airline system with the Canadian services over the inland route to Alaska. A service operating in Maine was recently extended to the Canadian Maritime Provinces. National defense was an important consideration in all these decisions. Agreements entered into by the United States and Canada in 1939 and in 1940 provide for continued close coöperation in authorizing additional air services between the two countries.

To the south, our international airlines in the West Indies and Latin America provide one of the most effective means for fulfilling the policy of the good neighbor among the American Republics. Recently several improvements have been made in the Latin American service. New, high altitude, high speed "strato-clippers" have been put in service between Miami and Panama and Miami and Rio de Janeiro. One day has been cut from the flying time on some of the through schedules, thanks to the friendly coöperation of the Brazilian Government in permitting the use of a straight route between Belem on the north coast and Rio. Other and more general improvements have been made along most of the trunk lines through the addition of schedules and reduction in operating time. I shall mention later the insidious and threatening activities of German airlines in South America which indicate the need for still further improvements in our own services.

As a broad gauge of the expansion of all United States airlines, we find that during 1940 the length of the routes over which our domestic and our international air carriers are authorized to fly increased 15 per cent. Airplane miles flown

by our domestic air carriers increased 31 per cent. and there was a similar substantial increase by our international carriers. These figures reflect not only the inauguration of new routes but also the operation of more airplanes, more miles over existing routes. Additional airplanes obviously were necessary to handle the greatly increased volume of mail and express, and especially the phenomenal increase in passenger traffic, which, during 1940 on the domestic airlines, exceeded one billion revenue passenger miles, surpassing the already impressive year of 1939 by 55 per cent. If this economically sound trend is to continue, our airlines must have a great many additional airplanes—and that is most improbable unless it can be shown that new transport airplanes for the airlines are at least as useful to our national defense and the nation's welfare as transferring those same airplanes to our Army or Navy or exporting them for use on foreign operated commercial airlines. Except for the temporary shortage of certain types of motors, completely stopping all production of airline transport planes evidently would not accelerate the production of purely military type aircraft to any appreciable degree.

The countries actively engaged in the present European war have discovered that it is vital to their welfare to maintain and even to expand their airline operations. I think most of the reasons for this could be classified under one or more of the three general headings of: first, direct participation in military maneuvers; second, maintenance of regular, rapid and reliable transportation; and, third, the spread of propaganda and subversive preparations for any subsequent open aggression.

There have been many public reports concerning the direct participation of German airline transport planes in military maneuvers, especially for carrying troops and their supplies. Limiting myself to those reports and without implying any official confirmation of them, it may be recalled that some troops were flown to Vienna when Germany took over Austria in 1938, but the first impressive use of the technique was in connection with the sudden invasion of Norway, and the results were stupendous and paralyzing! On that occasion, Junker airplanes of the Lufthansa airline were used side by

side with the military planes of the Luftwaffe to land the German army of occupation at Oslo and other points in Norway. Newspaper accounts describe the skies around Oslo as being black with these commercial aircraft, temporarily performing a military mission. Later, we read how parachute troops were dropped with their armament and supplies at certain airports and other points far in advance of the German ground forces when the Netherlands was invaded. And very recently press dispatches state that German airplanes have carried Italian reserve troops above the Adriatic to Albania and that vital supplies have had to be flown to Italian troops in Libya and Ethiopia because surface transportation was blocked. If these are useful indications, at all, then we certainly should have in being an adequate number of transport planes to meet any possible requirements of defense anywhere in the Western Hemisphere. But, the question must be answered as to whether we shall keep in production enough transport planes to sustain our airline operations and thereby produce a revenue with the equipment which would still always be available for national defense—or whether we shall, at the present time, add large numbers of transports directly to our military forces at the expense of obtaining sufficient numbers for our airline operations.

The American public probably is aware that the services now being performed by our airlines will become even more vital during any national emergency when there must be speed and mobility of regular transportation and communication, but I wonder if anyone yet has drawn any conclusions in this regard based on the latest information from Europe. These days many accurate facts cannot be made public and many alleged facts made public are not accurate, but I believe that the following information is substantially correct. In spite of the urgent requirements of the military air forces, England currently is maintaining its Empire air services at better than 90 per cent. of the pre-war basis. Some of our newest commercial transport planes are going to England—for example, three newly manufactured Boeing clipper planes similar to those now flying the Atlantic have just been released by Pan American Airways.

Lati, the Italian airline operating from Rome across the

South Atlantic to Brazil, has continued flying with remarkable regularity since its inauguration about a year ago, but there is little available information on how much of the former Italian airline operations in Europe have been maintained. The German airlines, despite temporary excursions into the realm of military operation, far from contracting, expanded, and in the first eight months of 1940 they were operating 110 per cent. more route miles than at the close of 1939. Of course, it is possible that operations for some reason were curtailed during the first few months of the war, but the point which should be emphasized is that instead of contracting, the German airlines apparently have more than doubled their service while at the same time actively participating in the conduct of war!

Now, let us turn to my third class of reasons why some airlines are being maintained even though their countries are engaged in war, namely the spread of propaganda and subversive preparations for any subsequent open aggression. In an earlier public address I stated: "Germany and Italy . . . not only have maintained various forms of aviation enterprises in Latin America but it is now evident that their plans are to be intensified and extended greatly in the near future. . . . It is not alone the fact that European airmen and aircraft are at our borders which should give us cause for thought and perhaps alarm. It, also, is the penetration into South America of pilots and mechanics who have been given training in diplomacy, languages, economics, foreign trade and politics. The time has passed when it can be doubted that aviation is being used by Germany and Italy as one of the means of winning vast trade markets and perhaps gaining a political foothold to the south of us. It is impossible for the United States longer to maintain faith in the security of geographical isolation, an isolation which no longer has any reality; for, with the infiltration into South America of European aircraft and airmen, the natural barrier of the Atlantic Ocean offers little or no protection."

That statement was made in December 1938. About the only changes which have taken place are the suspension of the South Atlantic service by Germany which has been replaced by one under Italian operation, and the opening of further

new airlines within South America by Germany. My statement was only a feeble cry in the wilderness of warnings on the deficiencies of our national defense. But, gradually our national interest in aviation and in defense was replaced by a hemisphere interest. We know now that to defend ourselves successfully, we must also help defend our friendly neighbors.

In his fireside chat a little over two weeks ago, the President stated: ". . . The width of these oceans is not what it was in the days of clipper ships. At one point between Africa and Brazil the distance is less than from Washington to Denver—5 hours for the latest type of bomber. . . . Any South American country in Nazi hands would always constitute a jumping-off place for German attack on any one of the other republics of this hemisphere."

That completes my interpretation of the three reasons why nations at war maintain and expand their airline operations. Although the new type of warfare may be as subtle and insidious as it is vicious and destructive, the lessons being learned by the participating nations cannot long escape our notice, and it might be assumed that then the continued expansion of our airline operations not only would be approved but would be encouraged as sound national defense policy. If that assumption be correct, then there remains only the question of whether additional airline service should be operated as a civil or as a military enterprise. Some very basic philosophies of our form of government are in the balance against the urgency of military requirements, but there are certain precedents and pronouncements of policy which can be followed in searching for an answer.

The maintenance of a definitely civil and private enterprise aviation industry has been a part of the basic policy of the United States since the Kelly Act of 1925. That policy is repeated in the Civil Aeronautics Act of 1938, which includes in its definition of public interest and public convenience and necessity "The encouragement and development of an air transportation system properly adapted to the present and future needs of the foreign and domestic commerce of the United States, of the postal service, and of the national defense."

In a message to the National Aviation Forum in January 1939, the President of the United States said:

"Civil aviation is clearly recognized as the backlog of national defense in the Civil Aeronautics Act which set up the effective machinery for a comprehensive national policy with respect to the air. . . . One fact which stands out is that hardly another civil activity of our people bears such a direct and intimate relation to the national security as does civil aviation. It supplies a reservoir of inestimable value to our military and naval forces in the form of men and machines, while at the same time it keeps an industry so geared that it can be instantly diverted to the production of fighting planes in the event of national emergency. . . ."

Certainly, if our civil aviation has been a backlog and a reservoir all these years, our national defense should consume whatever parts of it may be needed along with the military forces in the protection of our country. At such a time any part of civil aviation which is interfering with national defense should be suspended or abolished. In my opinion, however, this civilian industry, which is capable of self-support, does not need to be militarized into additional expenses for our taxpayers in order to meet threats to our security. American civil aviation as a decisive factor in world affairs should be given the fullest opportunity to stand side by side with our military forces as partners in national and hemisphere defense.

"Acid" Fear is a Bogey.—"We eat too many acid foods." is an unfounded idea in which many persons have firm faith. They proceed accordingly, and shun oranges, tomatoes and other good foods—for fear of acid. The taste is acid, but actually these foods and most other fruits and vegetables have the opposite effect when eaten. They tend to counteract acidity. There is no need to worry about acid-forming and base-forming foods, say the nutritionists of the Federal Bureau of Home Economics, if you have a well-rounded diet that includes plenty of milk, eggs, fruits, vegetables, and cereals with some meat, fish or poultry. It is better, they emphasize, to focus attention on adequate diets than to fret about acid-forming diets. Along the same line is the fancy about the danger of eating acid fruits and milk at the same meal. It is true that the acid fruits may curdle the milk, but the digestive juices of the stomach have the same effect. So it is perfectly safe to eat cherries and drink milk at the same meal, and to use orange juice in a milk drink. Another false food idea is that you should not eat different kinds of fruits together because there is danger in combining the different acids. Nutritionists explain that there is no possible harm in fruit combinations. Nature even combines different acids within a single fruit.

R. H. O.

Surface Water Supply.—Through the systematic recording of the flows of streams and rivers at more than 4000 river-measurement stations, the Geological Survey maintains up-to-date information on the nation's surface-water supply. In normal times, this supply means water-power for industry and irrigation water for agriculture, as well as water for municipal uses. Extreme deviations from the normal signify droughts or floods which affect the entire nation in varying degrees. It is now generally recognized that the various sections of the country are dependent one upon the other for an adequate water supply; conditions in the upper Ohio or the Red affect the subsequent flow of the Mississippi, the water-supply for industries along the Susquehanna is conditioned by the stream-flow of the Chemung. For this reason, there is increasing demand from agriculturists, industrialists, municipalities and various agencies for a report which will present an *over-all* picture of the country's water supply as reflected in the rivers and streams. Present-day demand is for information on a national scope. This the Geological Survey is now prepared to release in a monthly statement.

R. H. O.

A MECHANICAL METHOD FOR GRAPHICAL SOLUTION OF POLYNOMIALS.

BY

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ABSTRACT.

A mechanical synthesizer with thirty harmonic elements (fifteen sine components and fifteen cosine components) may be used to graph a polynomial in a complex plane. The sum of the sine components is recorded by a tracing point which moves vertically. The sum of the cosine components is recorded by horizontal motion of a drawing board.

Expansion of the polynomial by De Moivre's theorem expresses the function as a sum of sine terms and a sum of cosine terms. The polynomial may then be graphed by the machine, and thereby the complex roots determined. A number of typical curves are given to illustrate the machine method of determining real, imaginary, and complex roots.

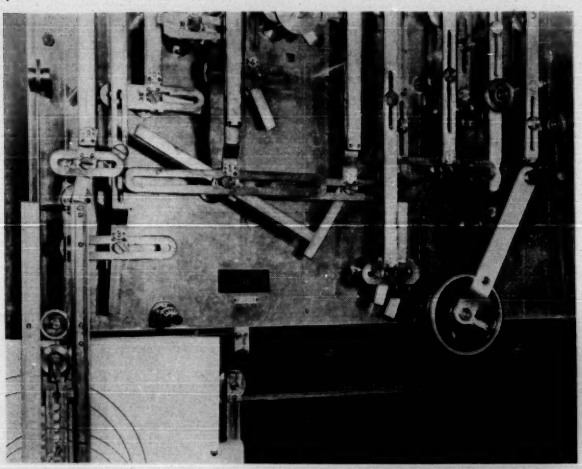
An auxiliary method is described which gives all the real roots of the polynomial from a single graph.

The solution of polynomials of high degree, especially when the roots are complex, involves difficult and laborious operations; and many methods of approximation have been developed. A machine method is herein described that facilitates the solution of polynomials as high as the fifteenth degree. Typical solutions are given to show mechanical methods of determining real, imaginary, and complex roots. In addition to the theoretical interest, there are many problems in physics and engineering of practical interest for which the mechanical method of approximation is applicable. The complementary solution of differential equations is an example of one type of such problems. The evident advantage of the method is the ease with which the function may be mechanically graphed.

The machine is essentially a synthesizer with fifteen sine components and fifteen cosine components. The multiple ratios of the sinusoidal motions are accomplished with a

train of gears of the proper pitch diameters; and the summation is accomplished by a chain and pulleys. The amplitude of each sine and each cosine component may be set independently. When the machine is used to determine complex roots of a polynomial, all fifteen of the sinusoidal displacements due to the sine components are communicated simultaneously to the chain that moves the pencil in a vertical direction; while all fifteen of the displacements due to the

FIG. 1.

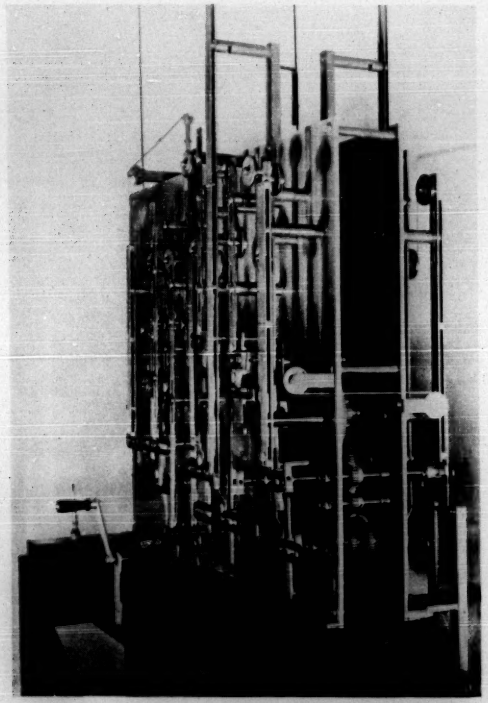


cosine components are communicated simultaneously to the chain that operates the drawing board in a horizontal direction. Or, either the contribution of the sine components or the contribution of the cosine components may produce vertical motion of the pencil; while the drawing board is driven in a horizontal direction by direct drive from the train of gears.

Figure 1 shows the drawing board, the suspended tracer block (that carries the pencil), the crank by which the train

of gears is driven, and the Scotch crossheads of the fifteen sine components. The fifteen cosine components are on the other side of the machine. Fig. 2 shows the train of gears

FIG. 2.



from which the Scotch crossheads are operated, a crosshead on each end of each of fifteen shafts. Further details of machine construction were given in a previous publication.[1]

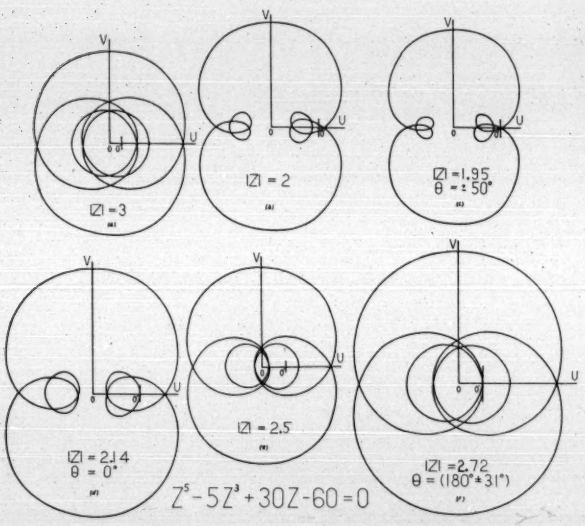
[1] S. Leroy Brown, JOUR. FRANK. INST., 228, 675–694.

COMPLEX ROOT METHOD.

Each term, a_kZ^k, of a polynomial may be expanded by De Moivre's theorem into $a_kr^k(\cos k\theta + i \sin k\theta)$. The transformation,

$$W = \sum_1^n a_k r^k \cos k\theta + i \sum_1^n a_k r^k \sin k\theta, \qquad (1)$$

FIG. 3.



allows each circle, r = constant, in the complex Z-plane to be conformally mapped onto the W-plane.[2] If a value, $Z_1 = r_1(\cos \theta_1 + i \sin \theta_1)$ = a root, lies on a circle, $r = r_1$, then the polynomial will have a value of zero at θ equal to θ_1. For this value Z, the curve in the W-plane, for r equal to r_1, will pass through the origin O' of the polynomial.

Therefore, the polynomial

$$a_nZ^n + a_{n-1}Z^{n-1} + \cdots a_kZ^k + \cdots a_2Z^2 + a_1Z + a_0 = 0 \qquad (2)$$

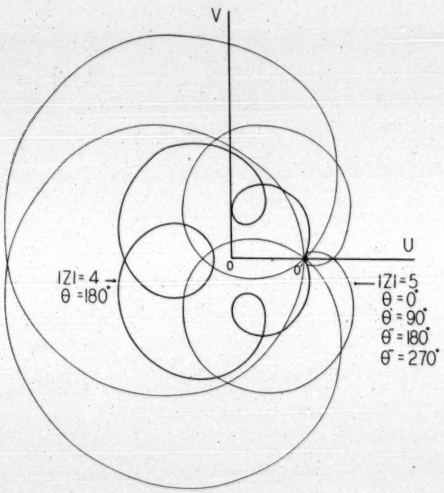
[2] A. J. Kempner, *Am. Math. Soc. Bulletin*, **41**, 809–843.

can be expressed as

$$W = \sum_{1}^{n} a_k r^k \cos k\theta + i \sum_{1}^{n} a_k r^k \sin k\theta = U + iV = -a_0. \quad (3)$$

This mapping in the W-plane may be done mechanically.[3] The method herein described and the illustrations that follow

FIG. 4.

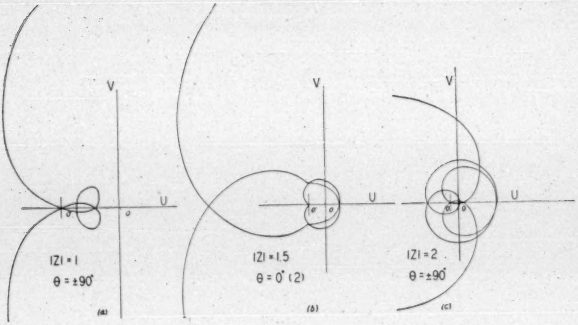


$$Z^5 + 4Z^4 - 625Z - 2500 = 0$$

show the adaptation of the harmonic synthesizer to this type of conformal mapping. Consequently, this adaptation furnishes practical means of determining the real and complex roots of a polynomial. It will be shown that this mechanical method is even applicable when the coefficients of the polynomial are complex.

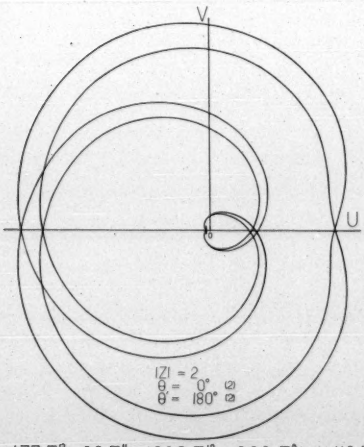
[3] R. L. Dietzold, *Bell Laboratory Record*, **16**, 130–134.

FIG. 5.



$$Z^4 - 3Z^3 + 7.25Z^2 - 15Z^3 + 15.25Z^2 - 12Z + 9 = 0$$

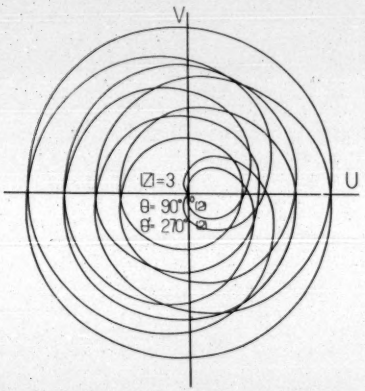
FIG. 6.



$$Z^{14} - 10Z^{13} + 177Z^{12} - 80Z^{11} + 1286Z^{10} + 660Z^9 - 11410Z^8 + 2560Z^7$$
$$- 41295Z^6 - 196890Z^5 - 329809Z^4 + 29520Z^3 - 497592Z^2 - 129601Z + 219024 = 0$$

The Scotch crossheads of both the sine and the cosine elements of the machine are set to the respective magnitudes of $a_k r_a^k$ (Eq. 1). As the fundamental makes one revolution, the angle θ takes on all values from zero to 2π. Thereby, equation (1) is graphed onto the (U, V) plane for the particular modulus r_a. If the values of a_k are real, then the setting of the kth harmonic element (sine and cosine) is accomplished by simply adjusting the pin of the crosshead to a displacement

FIG. 7.



$$Z^{14} - 10\,Z^{13} + 177\,Z^{12} - 80\,Z^{11} + 1286\,Z^{10} + 660\,Z^{9} - 11410\,Z^{8} + 2560\,Z^{7} - 41295\,Z^{6} - 19690\,Z^{5} + 329809\,Z^{4} + 29520\,Z^{3} - 497592\,Z^{2} - 12960\,Z + 219024 = 0$$

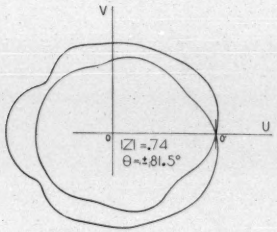
equal to the magnitude of $a_k r_a^k$. But, if the values of a_k are complex, the kth harmonic element (sine and cosine) must also be given an initial angular displacement equal to the angle of a_k.

The preceding general discussion serves as an introduction. A better understanding of the processes involved, their scope and limitations, and many details of manipulation will be given in the explanations of specific examples that follow.

Figure 3 illustrates the mechanical graphing of a fifth-degree polynomial for several values of the modulus $|Z|$ (r in Eq. 3). The encircling of the origin O' five times in Fig. 3(a)

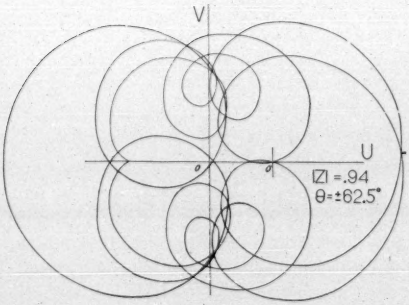
indicates that each of the five roots of this polynomial has a modulus less than 3. Separation of roots is obtained in (*b*) of this figure, two roots having moduli less than 2 and three

FIG. 8.



$$Z^{15}-5Z^{14}+17Z^{13}+\tfrac{5}{6}Z^{12}+\tfrac{2}{3}Z^{11}-10Z^{10}+3Z^{9}-2Z^{7}-4Z^{6}+Z^{5}$$
$$+Z^{4}-3Z^{3}-15Z^{2}-3Z-10=0$$

FIG. 9.

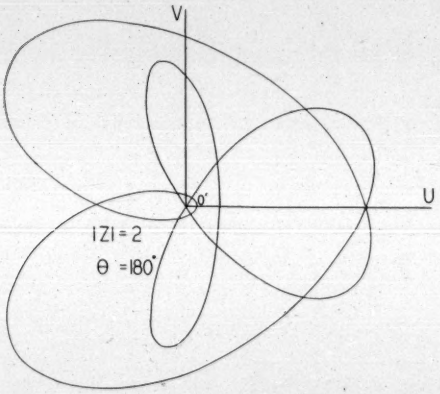


$$Z^{15}-5Z^{14}+17Z^{13}+\tfrac{5}{6}Z^{12}+\tfrac{2}{3}Z^{11}-10Z^{10}+3Z^{9}-2Z^{7}-4Z^{6}+Z^{5}$$
$$+Z^{4}-3Z^{3}-15Z^{2}+3Z-10=0$$

roots having moduli greater than 2 (but less than 3). Diagram (*e*) indicates further separation; that is, there are three roots with modulus less than 2.5.

Reducing the modulus to 1.95 (in (*c*)) locates two complex roots. The angles of these two conjugate roots are $\pm 50°$. These values of the angles were read from the dial on the machine as the tracing point went through the origin O'. The origin O may be described as the machine origin; that is, it is the position of the tracing point when there is no contribution from either the sine components (vertically) or the cosine components (horizontally). The constant term of the

FIG. 10.



$$Z^4 - Z^3 - 3Z^2 + 5Z - 2 = 0$$

equation (60 in this case) locates the position of O' which may be described as the origin of the polynomial.

A modulus of 2.14 (in (*d*)) locates a real root and a modulus of 2.72 (in (*f*)) locates two conjugate roots at $180° \pm 31°$.

Two traces are shown in Fig. 4 which determine the roots of another fifth-degree polynomial. One trace (the heavier curve) locates the real root of -4 and the other trace locates the remaining four roots of 5, $i5$, -5 and $-i5$.

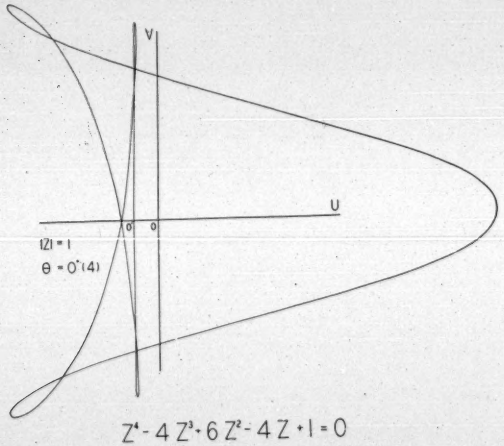
The curves for the solution of a sixth-degree equation are shown in Fig. 5. A large scale was used to improve the

accuracy and, consequently, only those portions of the curves that were needed were drawn. The roots are $\pm i$ (in (a)), two roots of 1.5 (in (b)), and $\pm i2$ (in (c)).

The trace in Fig. 6 determines four real roots of a four-teenth-degree polynomial; and four imaginary roots of the same polynomial are determined from the trace in Fig. 7.

The curve for the determination of two conjugate roots of a fifteen-degree equation is shown in Fig. 8; and the curve

FIG. 11.



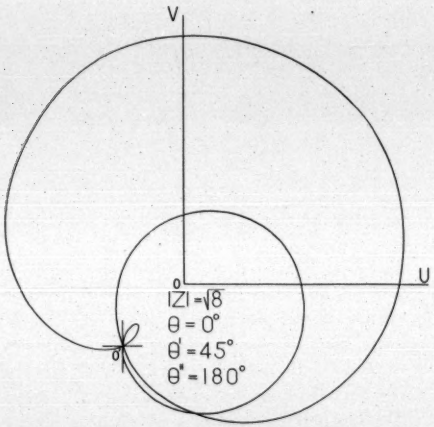
in Fig. 9 locates another pair of conjugate roots of this same equation.

Figure 10 is a trace that determines the root, -2, of a fourth-degree polynomial; the other three roots are multiple and of value one. The trace in Fig. 11 is for a fourth-degree equation that has four multiple roots of value one.

The solution of polynomials with complex coefficients is illustrated by the graph, in Fig. 12, of a cubic (with complex coefficients) that has real and imaginary roots. Since the constant term is complex, O' is no longer on the horizontal axis; and, since the coefficient of the second-power term has

an angle of 45°, it was necessary to set the second-harmonic sine and the second-harmonic cosine at an initial angle of 45° (and amplitude of $8\sqrt{8}$). In this example, all three of the roots, $\sqrt{8}$, $2 + i2$, and $-\sqrt{8}$ are determined by the single graph with a modulus of $\sqrt{8}$.

FIG. 12.



$$Z^3 - (2 + i\,2)\,Z^2 - 8Z + i\,16 + 16 = 0$$

REAL ROOT METHOD.

In this procedure, which is designated as the *real root method*, the variable Z of the polynomial (with real coefficients) is expressed in its complex form, $\rho(\cos \Phi + i \sin \Phi)$, with ρ variable for specific values of Φ. In the *complex root method*, which has already been discussed, ρ (r in Eq. 1) is held constant while Φ (θ in Eq. 1) is allowed to vary from zero to 2π. For all real values of Z, Φ will be zero (or π) and, consequently, Z will have the real value ρ (or $-\rho$).

Let $\rho = r \cos \theta$, where r is an upper bound for ρ, and θ is the angle through which the machine fundamental varies. Variation of θ from zero to π will cause Z to take on all values

from r to $-r$. Therefore, the real root values of the polynomial will be $r \cos \theta$ for certain values of θ between zero and π.

Substituting $Z = r \cos \theta$ in the polynomial (Eq. 2),

$$Y = \sum_1^n a_k r^k \cos^k \theta + a_0. \tag{4}$$

If the powers of $\cos \theta$ are expressed in terms of cosines of the multiple angles, $\cos^2 \theta = \frac{1 + \cos 2\theta}{2}$, $\cos^3 \theta = \frac{3 \cos \theta + \cos 3\theta}{4}$, $\cos^4 \theta = \frac{3 + 4 \cos 3\theta + \cos 4\theta}{8}$, etc.,

$$Y = \sum_1^n b_k \cos k\theta + b_0. \tag{5}$$

The summation $\sum_1^n b_k \cos k\theta$ may be graphed by the machine, and the real roots of the polynomial determined for values of the angle θ at which the summation is equal to $-b_0$.

The operation of the machine is such that the sum of the harmonic components is recorded by vertical movement of the pencil; while the drawing board is driven horizontally in direct ratio to θ. That is, the sum of the harmonic components is plotted against θ as the real value ($r \cos \theta$) of Z varies from r to $-r$.

The application of the machine to this method for determining the real roots of a polynomial will be shown in several specific examples that follow; and details are given to illustrate the important features involved. The outstanding feature is that all the real roots of a high-degree polynomial may be determined from a single graph.

The graph in Fig. 13 indicates that the roots of the cubic

$$Z^3 - Z^2 - 14Z + 24 = 0 \tag{6}$$

are 3, 2, and -4. Preliminary to setting the machine for the drawing of this graph, the equation is transformed by the substitution of $Z = r \cos \theta$. This gives

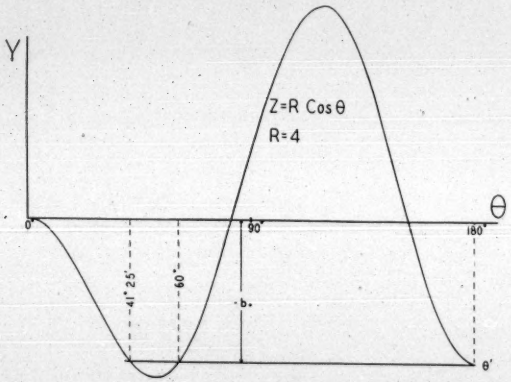
$$r^3 \cos^3 \theta - r^2 \cos^2 \theta - 14r \cos \theta + 24 = \theta, \tag{7}$$

$$\frac{3r^3\cos\theta}{4}+\frac{r^3\cos 3\theta}{4}-\frac{r^2}{2}-\frac{r^2\cos 2\theta}{2}-14r\cos\theta+24=0, \quad (8)$$

or

$$\frac{r^3}{4}\cos 3\theta-\frac{r^2}{2}\cos 2\theta+\left(\frac{3r^3}{4}-14r\right)\cos\theta+\left(24-\frac{r^2}{2}\right)=0. \quad (9)$$

FIG. 13.



$$Y=Z^3-Z^2-14Z+24$$

Choosing $r = 4$,

$$16\cos 3\theta-8\cos 2\theta-8\cos\theta+16=0. \quad (10)$$

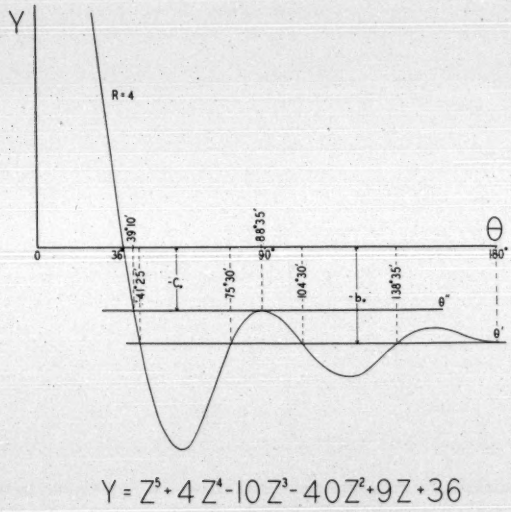
Therefore, the third harmonic cosine-component of the machine is set at an amplitude of 16, the second at an amplitude of -8, and the fundamental at an amplitude of -8. It is seen that the resultant curve has an ordinate of $-b_0$ (-16 in this case) for angles of 41°25′, 60°, and 180°. Consequently, the root values ($r\cos\theta$) are 3, 2, and -4.

The *real root method* is further illustrated by the diagram in Fig. 14; whereby, the roots of a fifth-degree equation,

$$Z^5 + 4Z^4 - 10Z^3 - 40Z^2 + 9Z + 36 = 0, \qquad (11)$$

are shown to be ± 1, ± 3, -4. Changing the constant term of the polynomial from 36 to -0.5 moves the curve axis (the axis for which Eq. 5 is zero) from θ' to θ''. The inter-

FIG. 14.



sections of the curve with the axis θ'' show the real roots of this equation,

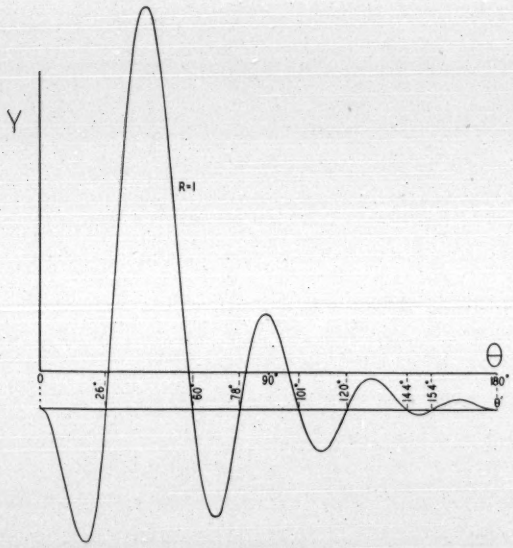
$$Z^5 + 4Z^4 - 10Z^3 - 40Z^2 + 9Z - .5 = 0, \qquad (12)$$

to be one of value 3.1 at 39°10′, and two of value 0.1 at 88°35′. The other two roots are a pair of conjugate roots. Note that O'' would have to be materially lower to give five real roots; that is, the constant in the equation would have to be greater than -0.5.

The solution of a ninth-degree equation is given in Fig. 15. The roots are $\pm.2$, $\pm.5$, $-.8$, $\pm.9$, and ± 1.

The nine real roots of an eleventh-degree equation are determined from the curve in Fig. 16. These real roots are the same as those found in the solution of the ninth-degree

FIG. 15.



$$Y = Z^9 + .8Z^8 - 2.1Z^7 - 1.68Z^6 + 1.345Z^5 + 1.076Z^4$$
$$- .253Z^3 - .2024Z^2 + .0081Z + .00648$$

equation of Fig. 15. In such a case, when all the roots are real except one pair of conjugate roots, this pair of complex roots may easily be found. In the general equation of a polynomial (Eq. 2), $-a_{n-1}$ is the sum of the roots, and $(-1)^n a_0$ is the product of the roots. Let $x + iy$ and $x - iy$ be the pair of conjugate roots in this example.

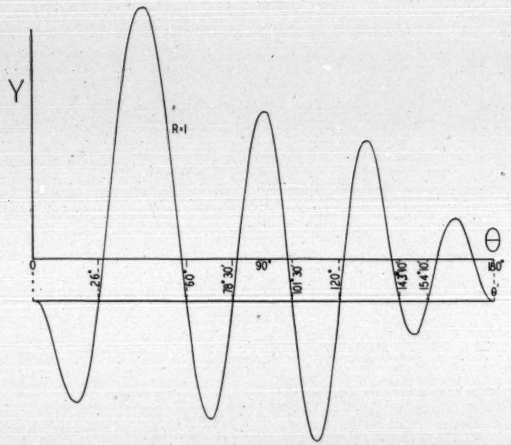
Then,

$$.8 = 2x - .8, \tag{13}$$

$$-.00648 = -.00648\,(x^2 + y^2), \tag{14}$$

$$x = .8 \text{ and } y = .6. \tag{15}$$

FIG. 16.



$$Y = Z^{11} - .8Z^{10} - 2.38Z^9 + 2.48Z^8 + 1.9329Z^7$$
$$- 2.75592Z^6 - .629572Z^5 + 1.278322Z^4$$
$$+ .078942Z^3 - 2.0888Z^2 - .002268Z$$
$$+ .00648$$

Curve A in Fig. 17 is the graph which determines the roots of a fifth-power equation,

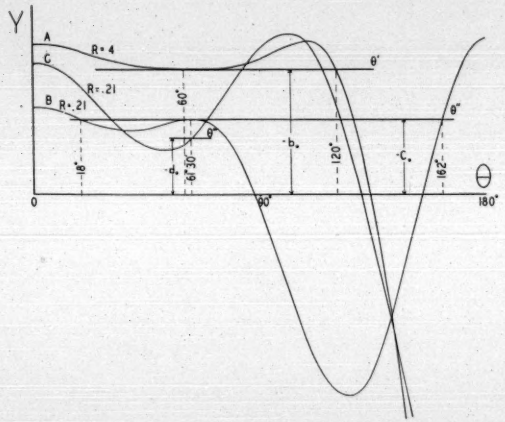
$$Z^5 - 6.2Z^4 + 8.77Z^3 + 16.068Z^2 - 51.0804Z + 34.9272 = 0, \tag{16}$$

when the upper bound was chosen as 4. The intersection with its axis θ' at 120° indicates a root of -2. The flat section

of the curve near 60° indicates other real roots which have nearly the same value, but the curve fails to resolve them. In such a case, it is possible to resolve these roots from a second equation that is derived from the original by reducing each of the roots by 2, (4 cos 60°). This equation with reduced roots is

$$Z^5 + 3.8Z^4 - .83Z^3 - .112Z^2 + .0316Z - .0016 = 0. \quad (17)$$

FIG. 17.



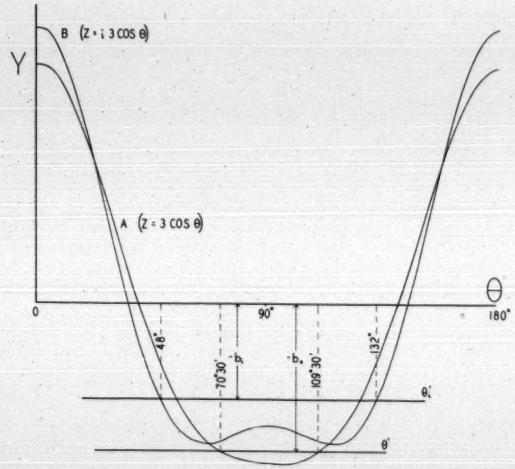
Curve B in Fig. 17 shows the roots of this derived equation to be .2, (.21 cos 18°); −.2, (.21 cos 162°); and two roots of value .1, (.21 cos 61°30′). Hence, the roots of the original equation are 2.2, 1.8, 2.1 (two), and −2.

Curve C in Fig. 17 is the graph which determines the roots of a fourth-degree equation which is the differential of equation (17); namely,

$$5Z^4 + 15.2Z^3 - 2.49Z^2 - .224Z + .0316 = 0. \quad (18)$$

At the double-root value, .1, the polynomial and its derivative have a factor $(x - .1)$, in common. The intersection of curve C with the axis O''' gives a more precise value for the double roots (.21 cos 61°30′) than could be obtained from curve B.

FIG. 18.



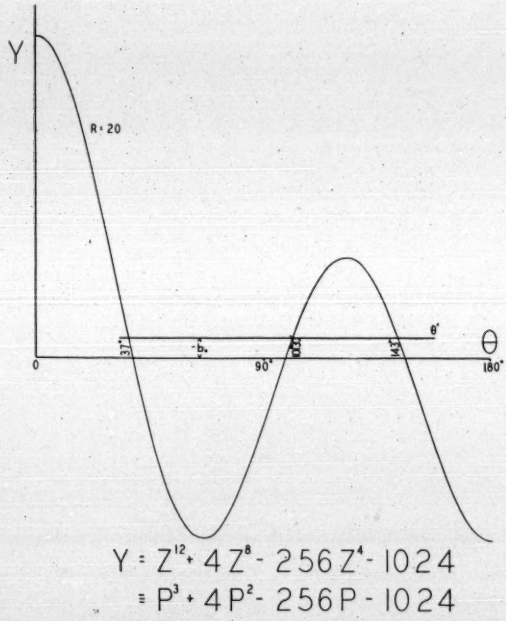
$$Y = Z^4 + 3Z^2 - 4$$

Figure 18 serves as a simple illustration of an application of the *real root method* whereby all the real roots of a polynomial with even powers may be determined from one graph (curve A), and all the pure imaginary roots from a second graph (curve B). Curve A shows the real roots to be ± 1, (3 cos 70°30′ and 3 cos 109°30′); and curve B shows that the imaginary roots are $\pm i2$, ($i3$ cos 48° and $i3$ cos 132°). It is evident that the roots in this simple illustration could be found by the quadratic formula; but the method herein used

is applicable where the degree of the equation is as high as fourteen (since the machine has fifteen harmonic elements).

A still further extension of the *real root method* is illustrated by the solution of a twelfth-degree equation in Fig. 19. All twelve of the roots (two real roots, two imaginary, and eight

FIG. 19.

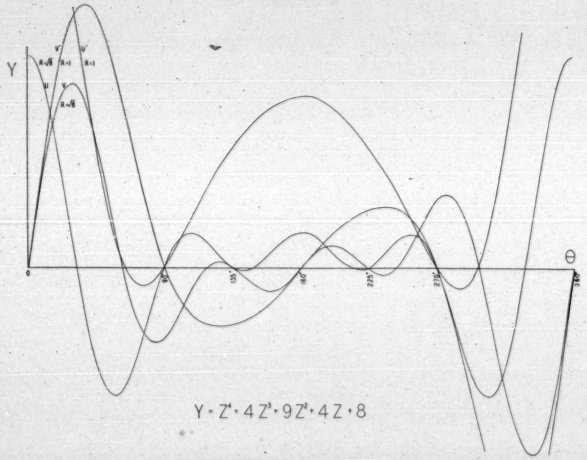


complex) are determined from the three real roots of a cubic which are shown to be ± 16, ($20 \cos 37°$ and $20° \cos 143°$) and -4, ($20 \cos 101°30'$) by the graph in this figure.

The transformation of a twelfth-degree equation of this type permits the twelve roots to be found by solving only a cubic. However, any polynomial (real coefficients) with even powers may be transformed to a lower-degree equation

(by letting $P = Z^2$), and all real and all pure imaginary roots of the original equation determined. The degree of the second equation cannot exceed fifteen (when the machine has but fifteen harmonic elements). Also, since any polynomial may be transformed into another whose roots are the fourth power of the roots of the original polynomial, any polynomial may be expressed as an equation of the type shown in Fig. 19. This last type may then be reduced (by letting $P = Z^4$), and

FIG. 20.



all real, all imaginary, and certain types of complex roots of the original polynomial determined (when the degree of the original polynomial does not exceed fifteen). The argument of all real roots is zero or π; the argument of all imaginary roots is $\pm\pi/2$; and the argument of those complex roots which can be found by this method is $\pm\pi/4$, or $\pm 3\pi/4$.

The final set of curves (Fig. 20) is not an example of either method as described and illustrated above, but furnishes another representation of a polynomial which may be graphed by the machine. The variation of the real part and

the variation of the imaginary part of a polynomial with the argument, θ (for a chosen modulus), is at least of theoretical interest. It will be noted that the intersection of a pair of these curves (when the proper modulus is chosen) on the θ axis locates a root of the polynomial.

One pair of curves (U, V) in Fig. 20 represents graphically the variations of the real and imaginary parts of a fourth-degree polynomial for a root-modulus of $\sqrt{8}$. The intersections of these two curves at 135° and 225° indicate the roots of $2 + i2$ and $2 - i2$. The second pair of curves (U', V') is graphed for a root-modulus of unity, and their intersections at 90° and 270° indicate the other two roots, $\pm i$.

It is assumed that the methods given are sufficiently illustrated to establish their practical usefulness; and the mechanical perfection of the machine is demonstrated in its application to the solution of polynomials.

Many-Valued Logics.—Seven years ago a physicist, DR. F. ZURICKY of California Institute of Technology, declared that he thought it would be easier to explain the atom if he could use a many-valued logic instead of the usual two-valued logic. By a many-valued logic he meant one which denies the principle of reductio ad absurdum. A many-valued logic states that instead of the two possibilities, in a precise and clear-cut statement of "so" and "not so," there are n possibilities. What are these possibilities? Who can say? They are simply called "possibility one," "possibility two," etc. When n is small, there might be a chance of saying what the possibilities are. For instance, when n is three, the possibilities might be "so," "not so," and "undecidable." And so on. However, questions which can be answered in such a way have always dealt with realms where the phenomena are vague. A general question such as "Do you favor short skirts for women?" might well receive six answers varying from "certainly" to "certainly not." However, the fundamental tenet of a many-valued logic is that not only general questions, but even the most precise and clear-cut statement may fall into any one of n possible cases. Before Dr. Zuricky's suggestion, a many-valued logic had been considered by mathematicians as a rather interesting game, but hardly worth intensive study. However, Dr. Zuricky seriously requested that mathematicians get busy and develop many-valued logics for use in explaining the atom, and since that time some systematic work has been done on the probelm. This work was reported on before the recent meeting of the American Mathematical Society at Wayne University, Detroit, Michigan, by Professor J. BARKLEY ROSSER of Cornell University, who told of results that he and others had obtained. The principal result so far is that a many-valued logic turns out to be much more complicated than anyone had expected. The reason for this is that the meaning of every mathematical word depends on the fact that one uses a two-valued logic for ordinary mathematics. Allow more values, and you get more meanings for every word. What nobody had suspected was that you get a great many more meanings for every word. All this complication makes things hard for the mathematician, but allows more freedom for the physicist. For instance, it was found that in a three-valued logic, there are 256 distinct meanings of the simple word "and." Imagine how many possible kinds of atoms a physicist could make out of electrons AND protons with 256 kinds of "and" to choose from, and how much more chance he'd have of finding one that worked the way it ought to.

R. H. O.

THE DIELECTRIC PROPERTIES OF RESIN-OIL MIXTURES.

BY

J. B. WHITEHEAD and J. J. CHAPMAN.

INTRODUCTION.

Resin-oil mixtures are commonly used as impregnants of paper insulated high voltage underground cables. The chief object in view in the addition of resin to the refined petroleum oil is to increase its viscosity, elevate its pour point, and increase adhesion to the paper fibres. These properties are important for the prevention of movement of the saturant following original impregnation. Experience has shown that the addition of the resin does not cause serious increases in the dielectric loss, and it is commonly accepted that it results in an improvement of the long-time stability of the cable insulation.

The purpose of the present studies is to examine the origin and nature of the electrical properties of resin-oil mixtures with special reference to the question whether the polar properties of resin play a part in the resulting mixture. Thus light will be thrown on the question whether the well-known electrical properties of impregnated paper have a polar origin as sometimes suggested.[1, 2, 3] Only one oil and one grade of resin have been used, but, as shown by Sommerman,[4] who has examined a wide variety of combinations of oil and resin, the general characteristics of all of them are much the same, except as to differences in numerical values. Sommerman's thorough studies were directed to the physical properties of the mixtures as related to cable structures and stability.

The Resin.—Commercial abietic acid ($C_{20}H_{30}O_2$), or resin, is solid and brittle at ordinary temperatures and passes through stages of slowly decreasing viscosity to a free liquid condition at about 120° C. A study of the 60 cycle properties of resin over a limited range of temperature (20° to 100° C.) has been reported by one of the present authors.[5] Below 40° C., changes in the value of dielectric constant suggest

the presence of polar behavior, or, equally, an interfacial polarization due to the simultaneous presence of both liquid and solid phases. The present studies of oil-resin mixtures have employed resin from the same commercial source. The mixtures were all in liquid form.

The Oil.—The electrical properties of refined petroleum oils, as commonly used for impregnated paper insulation, have been extensively studied and are fairly well understood. As shown particularly by one of the present authors, variations in dielectric loss, power factor, and capacitance are in most cases completely accounted for by an ionic conductivity and a dielectric constant of uniform value over a wide range of frequency. The single oil used in the present studies is a typical example. It has approximately the same characteristics as Sommerman's oil No. 0–3. The manufacturer's data are: specific gravity 23.2° Baumé, flash point 525° F., viscosity 144 Saybolt at 210° F., pour point 0° F.

MEASUREMENTS.

Test Cell.—The measurements were made on liquid layers 1.5 mm. thick between coaxial cylindrical electrodes, equipped with guard rings and protective screening, and immersed in constant temperature vacuum tanks.[6]

Schering Bridge.—Measurements of 60 cycle power factor and dielectric constant were made on a Schering bridge, already described in foregoing papers [7] and slightly modified for the special requirements of this work. The power factor sensitivity is roughly of the order 5×10^{-6}. The 60 cycle a.c. supply had a smooth wave closely approximating true sine shape.

The same bridge with slight modifications was used for measurements of dielectric constant and power factor in the range of frequencies 5 to 50 kc.

Quadrant Electrometer.—A Dolezalek quadrant electrometer was used to measure time changes of the conductivity of the test samples over the range 15 sec. to 40 min., and at stresses up to 25 volts per mil.

Amplifier-Oscillograph.—An essential feature of the work is the measurement of the initial conductivity of the test samples, that is to say, the value of the conductivity during

the interval from one or two milliseconds following the application of 1500 volts continuous potential. This is accomplished by the combination of an electromagnetic oscillograph, a three-stage vacuum tube amplifier, and a rapid acting switch, as commonly used by one of the authors and described by Waldorf.[8]

OIL-RESIN MIXTURES.

The resin was broken into a combination of small lumps and powder and gently heated in a pyrex flask, under a vacuum of 1 mm. Hg and to a final temperature after two hours of 110° C. As the resin slowly melted, there was a copious evolution of gas, causing a thick foam above a clear, amber colored liquid. With occasional agitation, and after no further evolution of gas, the melted resin was kept at approximately 110° C. for one hour and then allowed to cool under vacuum to 50° C., at which temperature the resin was solid. The vacuum was then released for a few minutes, the oil immediately poured in, and the vacuum then restored. The oil was received from the manufacturer under an atmosphere of nitrogen, and was never exposed to air except for the brief period to shift to the resin flask. The combination is then slowly heated under vacuum, the dissolved nitrogen is first given off, and at about 80°C. the resin begins to disappear into the oil. At 110°C. the mixing was complete and the flask maintained at this temperature for one hour with occasional heating and shaking. It was then allowed to cool to 40°C. The mixture was then passed through a 200 mesh screen and sprayed into the measuring cell, which was maintained at a vacuum of 1 mm. Hg, and a temperature of 80° C.

Volume and Density of Mixtures.—It was found that volumes of resin and of oil were exactly additive, that is, 5 cc. of resin and 10 cc. of oil gave a volume of 15 cc. of mixture. By measuring the densities of the resin and of the oil, it was possible to predict the density of any mixture to within approximately 0.3 per cent., thus affording good evidence of the additive law of volumes. The density determinations of the liquids were made with a picnometer and a chemical balance. The density of the solid abietic acid or resin was obtained by melting some of the powder into a test tube and

filling to a predetermined mark and weighing. Table I gives the measured values of density for mixtures up to 20 per cent.

TABLE I.

Check of Additive Law of ε.

20 Per Cent. Mixture.

Temp. Deg. C.	ε_2	ε_1	d	d_2	ε	
					Computed	Observed
30	2.91*	2.280	0.934	1.006	2.399	2.410
60	2.880	2.245	0.910	0.992	2.362	2.371
80	2.856	2.223	0.897	0.982	2.339	2.341
100	2.825	2.200	0.883	0.973	2.314	2.312
			10 Per Cent. Mixture.			
30	2.91*	2.280	0.923	1.006	2.339	2.343
60	2.880	2.245	0.901	0.992	2.303	2.307
80	2.856	2.223	0.888	0.982	2.280	2.278
100	2.825	2.200	0.875	0.973	2.256	2.251
			5 Per Cent. Mixture.			
30	2.91*	2.280	0.920	1.006	2.309	2.310
60	2.880	2.245	0.897	0.992	2.274	2.271
80	2.856	2.273	0.885	0.982	2.252	2.245
100	2.825	2.200	0.872	0.973	2.228	2.222

* Extrapolated value.

by weight of resin, and corresponding values as computed from the formula:

$$d = \frac{d_1 d_2}{N(d_1 - d_2) + d_2}, \qquad (1)$$

in which d_1 and d_2 are the densities of the mixture of the oil and of the resin respectively, and N is the per cent. by weight of resin in the mixture. The mixtures were also examined for coefficient of volume expansion between 30° and 120° C., and it was found that the expansion was linear with temperature increase over the entire range. The above results indicate the absence of any chemical combination between oil and abietic acid molecules. Further evidence will be found in the additive behavior of the dielectric constant. The addi-

tive property in the case of both densities and dielectric constants points strongly to the absence of chemical combination.

Following the procedure described above, mixtures up to 20, 25, and 30 per cent. resin were made. It was found, however, that on standing for one or two weeks at room temperature, small abietic acid crystals formed in the case of the 30 per cent. mixture, and were present in small amount in the 25 per cent. mixture. They were apparently entirely absent in the 20 per cent. mixture. In order to avoid possible interfacial effects between the liquid and solid phases, the electrical measurements were therefore confined to mixtures up to 20 per cent. resin.

EXPERIMENTAL RESULTS.

Viscosity.—The variation of viscosity with temperature and with per cent. resin is shown in Fig. 1. It is seen that the increase of viscosity with percentage abietic acid is practically linear, except in the low temperature range. The viscosity ratio, that is the ratio of values at 100° F., and 210° F., is quite high. The viscosity-temperature curve does not obey the exponential law over the entire range; Gemant attributes such deviations to changes in molecular structure. The product of viscosity and conductivity has been proposed by one of the authors [9] as a measure of ionic content, this product having been found to be nearly constant for each of a large number of oils in the temperature range 30° to 60° C. This law was also found to be approximately true for the pure oil used in these tests.

Dielectric Constant-Temperature.—The variation of dielectric constant with temperature and at 60 cycles is shown in Fig. 2 in the range 30° to 120° C. The dielectric constant for the pure oil and for each mixture decreases linearly with increasing temperature. The rate of decrease is greater with increasing resin content, owing to the increase in the density of the mixture, in accordance with equations (2) and (3) below.

Using the same data, the relation between dielectric constant and per cent. resin are plotted for four temperatures in Fig. 3. Here again we see an approximately linear increase of dielectric constant with per cent. resin content by weight. The slight departure from linearity for low values of resin

FIG. 1.

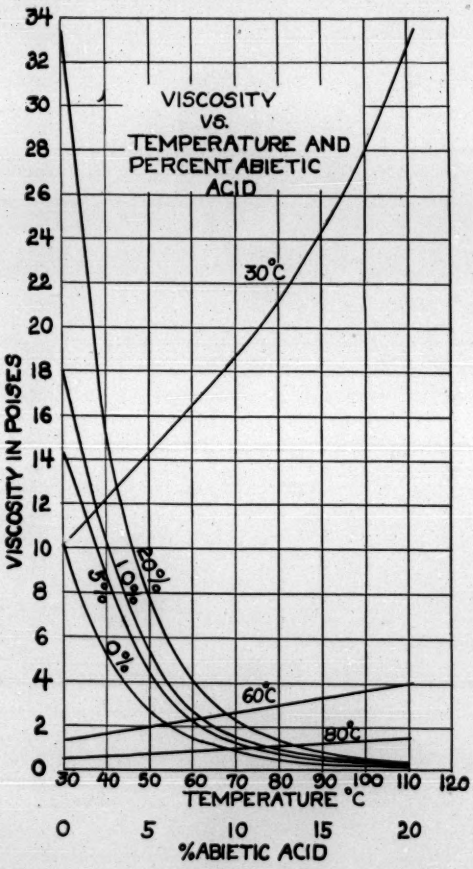
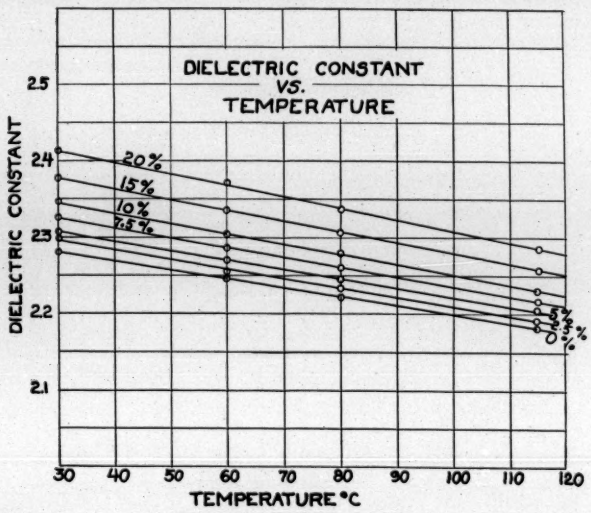

VISCOSITY
VS.
TEMPERATURE AND
PERCENT ABIETIC
ACID
VISCOSITY IN POISES
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
30°C
60°C
80°C
20%
10%
5%
0%
30 40 50 60 70 80 90 100 110 120
TEMPERATURE °C
0 5 10 15 20
%ABIETIC ACID

FIG. 2.



content is again caused by the slight variation in the over-all density of the mixture, as follows:

Let n = fraction by volume occupied by resin,
N = fraction by weight of resin.

Let ϵ, ϵ_1, and ϵ_2, and d, d_1, d_2, be the dielectric constants and the densities of the mixture, the oil and the resin respectively; then

$$\epsilon = (1 - n)\epsilon_1 + n\epsilon_2 = \epsilon_1 + n(\epsilon_2 - \epsilon_1), \qquad (2)$$

which gives the variation of ϵ with n; this is the additive law on the basis of n as volume percentage. Also,

$$n = N\frac{d}{d_2},$$

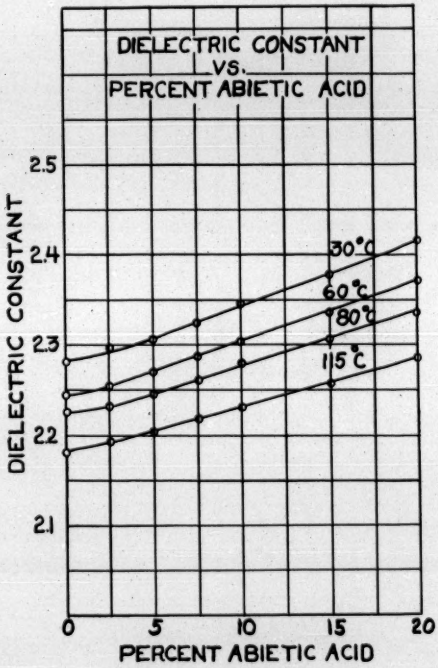
whence

$$\epsilon = \epsilon_1 + N\frac{d}{d_2}(\epsilon_2 - \epsilon_1), \qquad (3)$$

which gives the variation of ϵ with N; this is the additive law on the basis of N as weight percentage.

Inspection of equation (3) shows that if d were constant, the relation between ϵ and N would be linear. However,

FIG. 3.



with decreasing value of N, d decreases less and less rapidly, giving the slight deviation a linearity indicated in Fig. 3, particularly below the value 5 for N. The experimental results are compared with equation (3) in Table I. The values of ϵ_2 for the range of temperature studied are those obtained by one of the authors in a separate study of the same abietic

acid.[5] From Table I it is seen that the agreement between experiment and equation (3), based on the additive law, is extremely close (within 0.4 per cent. over the entire ranges of temperature and per cent. resin content).

Dielectric Constant-Frequency.—The dielectric constant of the pure oil and for the 5 and 15 per cent. mixtures was measured over the range of frequency 60 to 50,000 cycles, and up to 80° C. The results are plotted in Fig. 4. The dielectric constant showed no departure from constant value between 60 and 50,000 cycles, that is to say, there is no anomalous dispersion of dielectric constant within this range of frequency. This fact has important bearing on the question of the part played by the polar properties of resin in resin-oil mixtures at commercial power frequencies. Further reference to it will be found in the discussion below.

If each of the oils is assumed to have a constant aggregate molecular weight for the range of temperature 30° to 115° C., the Clausius-Mosotti relation of equation (4) may be used for computing the value of the molecular polarization.

$$P = \frac{M_x}{d} = \frac{(\epsilon - 1)}{(\epsilon + 2)}, \qquad (4)$$

where P = molar polarization,
M_x = molecular weight of mixture x per cent.,
d = density,
ϵ = dielectric constant.

For a polar substance, P should increase linearly with $1/T$, T being the absolute temperature, but for a non-polar substance P should remain constant. Applying the data of Fig. 2, to equation (4), we find that P is constant within 0.5 per cent. for the mixtures containing the larger percentages of resin. In the pure oil P is about 2 per cent. higher at 115 degrees than at 30 degrees. This suggests that it is incorrect to assume that the oil has a fixed molecular structure and constant molecular weight M_o over this range of temperature. It is well known that oils of this type are in fact mixtures of a number of different hydrocarbon molecules.

Power Factor and D.C. Conductivity.—In Fig. 5 the power factor at 60 cycles is plotted against temperature for the vari-

FIG. 4.

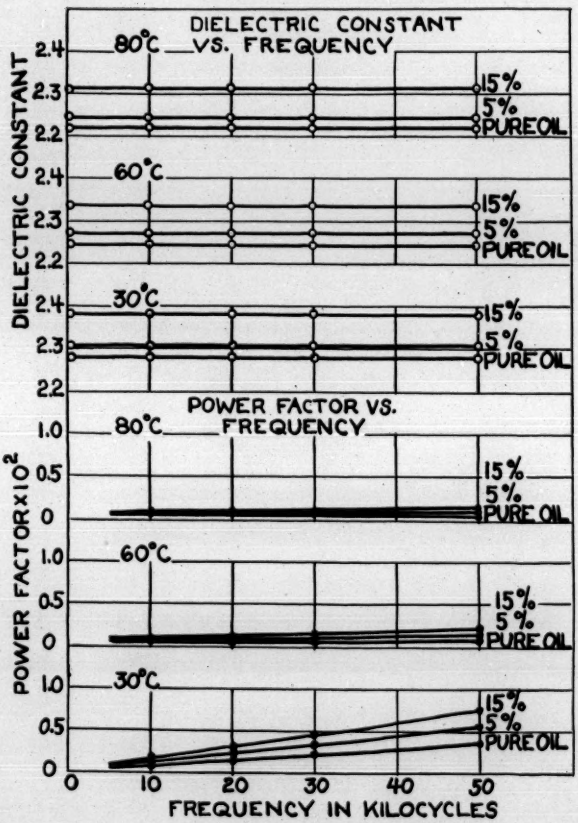
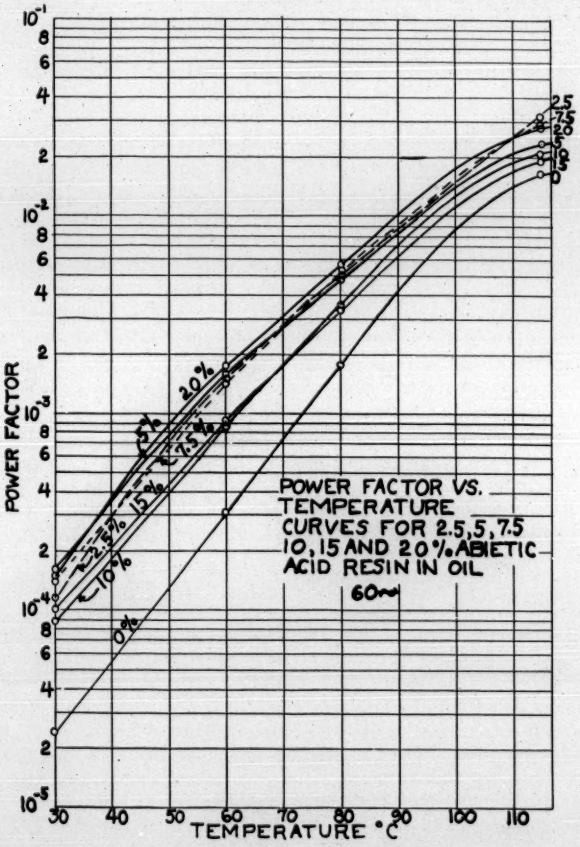

DIELECTRIC CONSTANT VS. FREQUENCY
80°C
60°C
30°C
15%
5%
PURE OIL
DIELECTRIC CONSTANT
2.4
2.3
2.2
POWER FACTOR VS. FREQUENCY
POWER FACTOR×10²
1.0
0.5
0
0
10
20
30
40
50
FREQUENCY IN KILOCYCLES

FIG. 5.


POWER FACTOR
TEMPERATURE °C
POWER FACTOR VS. TEMPERATURE CURVES FOR 2.5, 5, 7.5 10, 15 AND 20% ABIETIC ACID RESIN IN OIL
60~
2.5%
5%
7.5%
10%
15%
20%
0%

ous mixtures. Power factor as ordinate is plotted to a logarithmic scale. The resulting curve for the oil alone is a straight line up to nearly 100° C., but those for the various mixtures depart from the linear relation above 50° and 60° C. Consequently, the general experimental relation of conductivity and power factor to temperature obtains over only a limited range for the mixtures here studied. In Fig. 6 power factor is plotted in similar fashion against per cent. resin content for four values of temperature. In Figs. 7 and 8 the continuous current at 1500 volts d.c. after one minute and after 40 minutes respectively are plotted on the same basis. Note particularly the similarity in shape of the curves of Figs. 6, 7, and 8, indicating that notwithstanding irregular variation with resin content, power factor and dielectric loss are predominantly conduction phenomena and due to ionic motion.

In Figs. 9 and 10 is shown the current in amperes at 1500 volts d.c. as function of the time in minutes at which the conductivity is measured, both to logarithmic scale, and for four temperatures. The solid lines of these curves give the measurements with the electrometer. The broken lines are carried through the single points indicated by small triangles, as computed from the bridge measurement of power factor, assuming that the dielectric loss is entirely due to conduction. Similar curves were taken for each of the other mixtures.

In these measurements the d.c. voltage was applied immediately after the bridge measurement and was removed after 40 minutes. A steady electrometer measurement was always possible 20 sec. after the application of d.c. voltage. A period of 24 hours was allowed between successive d.c. measurements to avoid disturbance due to space charge separation.[10] At 1500 volts the stress on the sample was about 25 volts per mil. Measurements at lower values of voltage indicated that there was no departure from Ohm's law, either for the conductivity or the power factor measurements within this range.

As a further check on the conclusion that 60 cycle power factor is accounted for by initial conductivity, measurements of the latter were also made using the electromagnetic oscillograph. A typical oscillogram on a 15 per cent. mixture at

FIG. 6.

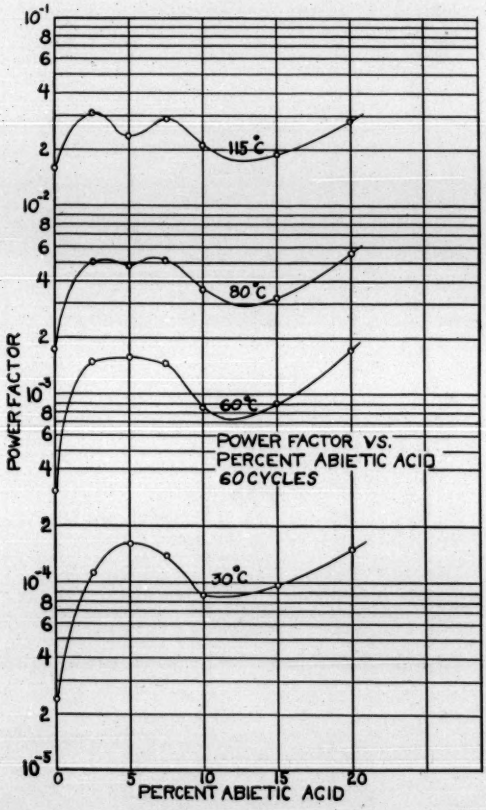

POWER FACTOR
PERCENT ABIETIC ACID
115°C
80°C
60°C
30°C
POWER FACTOR VS.
PERCENT ABIETIC ACID
60 CYCLES
0
5
10
15
20

FIG. 7.

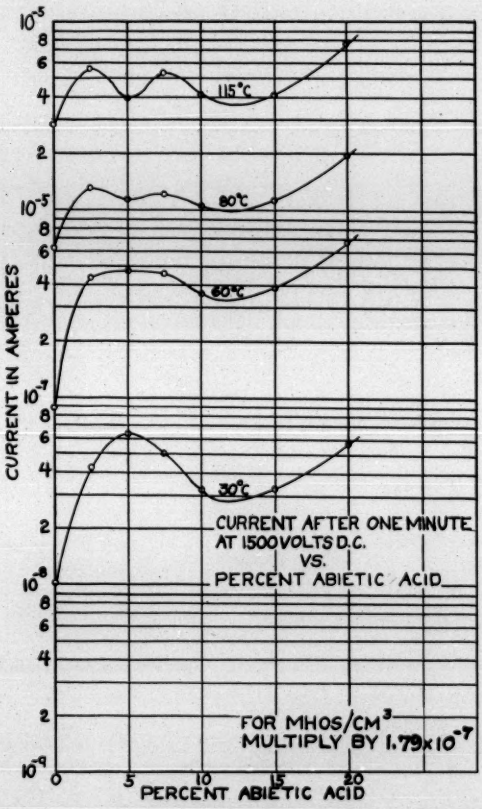

CURRENT IN AMPERES
115°C
80°C
60°C
30°C
CURRENT AFTER ONE MINUTE
AT 1500 VOLTS D.C.
VS.
PERCENT ABIETIC ACID
FOR MHOS/CM³
MULTIPLY BY 1.79x10⁻⁷
PERCENT ABIETIC ACID

FIG. 8.

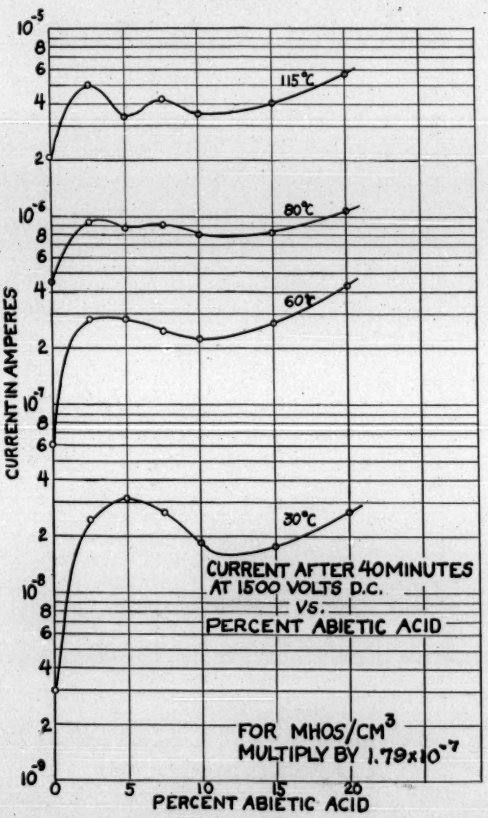

CURRENT IN AMPERES
115°C
80°C
60°C
30°C
CURRENT AFTER 40 MINUTES
AT 1500 VOLTS D.C.
VS.
PERCENT ABIETIC ACID
FOR MHOS/CM³
MULTIPLY BY 1.79x10⁻⁷
PERCENT ABIETIC ACID

FIG. 9.

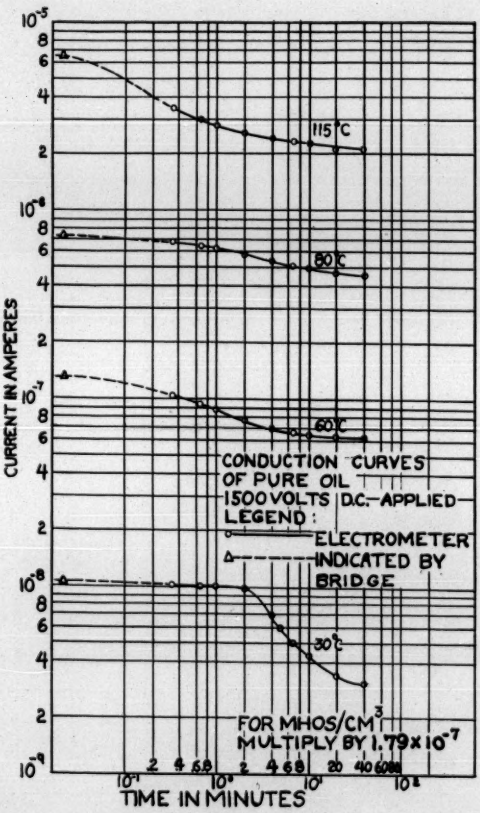
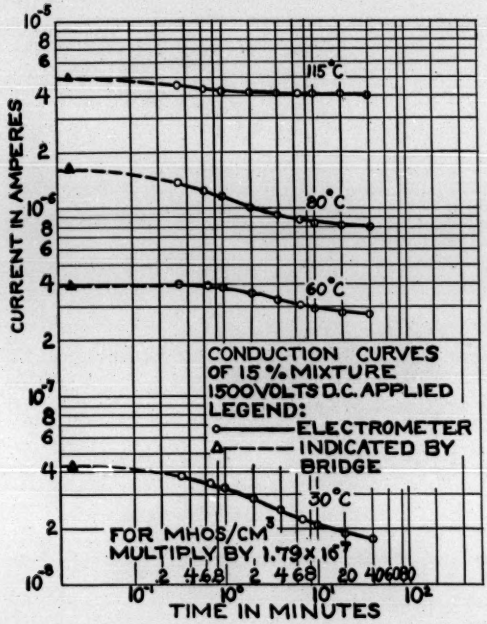

CURRENT IN AMPERES
TIME IN MINUTES
115°C
80°C
60°C
30°C
CONDUCTION CURVES OF PURE OIL 1500 VOLTS D.C. APPLIED
LEGEND:
ELECTROMETER
INDICATED BY BRIDGE
FOR MHOS/CM³ MULTIPLY BY 1.79 x 10⁻⁷

FIG. 10.



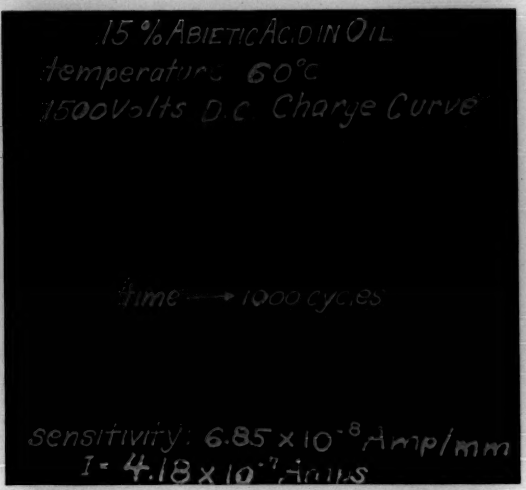
60° C. is shown in Fig. 11. Similar oscillograms were taken at other temperatures and all show the initial flat region following the short circuit of the circuit transient, thus indicating a constant value of conductivity over and beyond the range of the oscillogram. Table II gives the resulting values

TABLE II.

15 Per Cent Resin.

P.F. by Bridge	P.F. by Oscillograph Data	Temp. Deg. C.
1.02×10^{-4}	1.00×10^{-4}	30
8.86×10^{-4}	8.70×10^{-4}	60
3.52×10^{-3}	3.50×10^{-3}	80
9.85×10^{-3}	1.00×10^{-2}	100

FIG. 11.


15% ABIETIC ACID IN OIL
Temperature 60°C
1500 Volts D.C. Charge Curve
Time → 1000 cycles
Sensitivity: 6.85 × 10⁻⁸ Amp/mm
I = 4.18 × 10⁻⁷ Amps

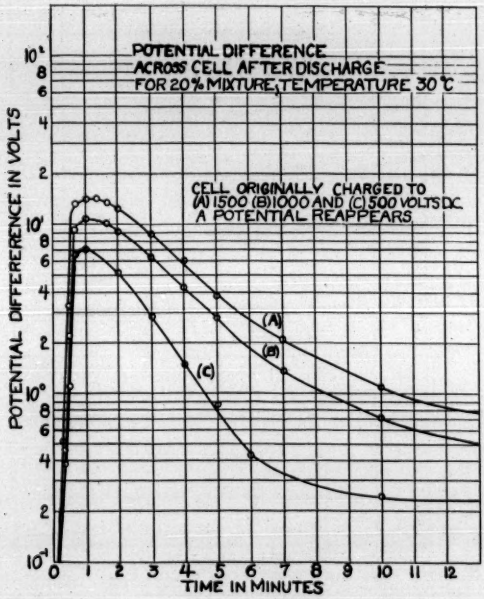
of power factor as measured by the bridge and as computed from the conductivity measured in Fig. 11. These data show conclusively that irreversible conduction accounts for the 60 cycle power factor.

Residual Charge.—Fig. 12 shows for a 20 per cent. mixture the rise in potential across the open cell, after 40 minute periods of charging at (*a*) 1500, (*b*) 1000, (*c*) 500 volts d.c. followed in each case by a very brief short circuit for dissipating the geometric charge. As ordinate the potential difference in volts is plotted to a logarithmic scale; as abscissæ time in minutes to a linear scale. The initial rise is a straight line, indicating an exponential increase of potential difference.

As seen, the maximum potential difference increases with the value of the charging voltage and in all cases thereafter decreases ultimately to zero. The charges on the plates recombine through the conductivity of the dielectric. The phenomenon takes place with diminished magnitude, and the initial rise is greater as the temperature increases. The max-

ima reached are in general lower with decreasing resin content. With the method of observation here used, namely direct reading of the quadrant electrometer, the phenomenon could not be detected in the case of the oil alone. The initial rise of potential difference in Fig. 12 corresponds to a current

FIG. 12.

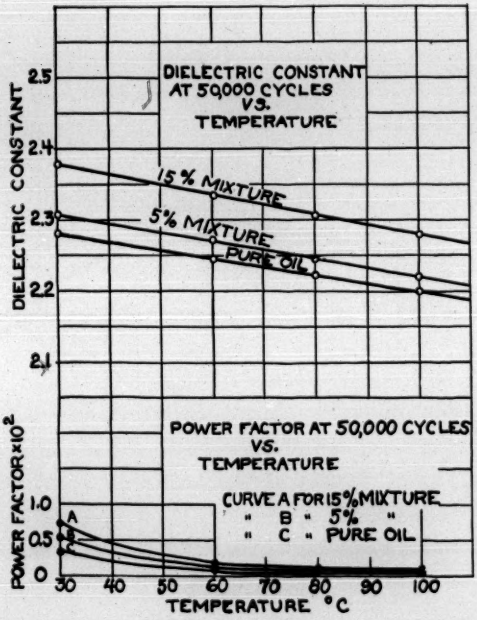

POTENTIAL DIFFERENCE ACROSS CELL AFTER DISCHARGE FOR 20% MIXTURE, TEMPERATURE 30°C
CELL ORIGINALLY CHARGED TO (A) 1500 (B) 1000 AND (C) 500 VOLTS D.C. A POTENTIAL REAPPEARS.
POTENTIAL DIFFERENCE IN VOLTS
TIME IN MINUTES
(A)
(B)
(C)

flow of about 10^{-11} amperes. This value is too small for detection even by a sensitive galvanometer, and is quite outside the low limit of sensitivity of the amplifier oscillograph. Phenomena of this character have, however, been observed in a number of cases of insulating oils and are commonly attributed to the accumulation of space charge either at the surface of the electrodes. or as volumetric distribution in the

liquid.[10, 11, 12] The motions of these space charges on discharge are known to be quite slow. The resin oil mixtures seem to afford an example of the phenomenon much more pronounced than any heretofore observed.

Measurements up to 50 Kc.—In Fig. 4 are shown some of

FIG. 13.



the results of measurements over the range 60 to 50,000 cycles, for the pure oil, and for 5 and for 15 per cent. resin mixtures. As already noted, there is no anomalous dispersion of the dielectric constant over the whole range of frequency for any one of the liquids, nor at any one of the three temperatures indicated. This indicates that the polar contribution of the resin to the dielectric constant does not vary over the

range of conditions cited. The increase in the value of dielectric constant with increasing resin content, and its decrease with increasing temperature, for any one mixture, are in general accord with the behavior at 60 cycles as already described.

However, in the case of power factor, there is evidence of an increase of value with increase of frequency for each of the three liquids and at each temperature. The increase of power factor with frequency decreases markedly with increasing temperature, as shown also in Fig. 4. The power factor behavior with frequency seems to indicate the beginnings of an approach to a maximum at some higher value of frequency. Similarly, in Fig. 13 a maximum of the 50 kc. power factor is indicated for some temperature below 30° C. These relations suggest on the one hand an increase of dipole loss with further increase of frequency, and on the other, due to viscosity or internal friction, anomalous dispersion of dielectric constant at low temperatures. However, the change in dielectric constant is usually very much more abrupt than that of power factor and the variation of the latter is spread over a much wider range.[13] In the present case the power factor begins its upward trend at frequencies and temperatures at which no change is yet apparent in the dielectric constant.

DISCUSSION

The outstanding features of the above results are the additive character of the volumes of mixtures of oil and resin, the absence of any frequency variation of dielectric constant, and the evidence that power factor and dielectric loss are due to ionic conductivity.

The additive law for the volumes, together with the summational behavior of the dielectric constant of the mixtures, indicates that the solution of resin in oil partakes more of the nature of a physical mixture than of a chemical combination. In fact, there is complete absence of suggestion of the latter.

The frequency and temperature behavior of the dielectric constant indicate clearly the absence of the variations typical of polar substances, and now commonly described [1] as "anomalous dispersion." This does not mean that the resin molecule does not have polar properties, but that within the range

of frequency and temperature studied, the contribution of the polar molecule to dielectric constant is itself constant and uniform, and not affected in appreciable degree by the variations of internal friction. Additional support is given to this view by the application of the Clausius-Mosotti relation of equation (4). It is now known that this relation gives good results when applied to electronic and atomic polarizations, but that departures are to be expected in other cases.[14] Good agreement has been found for the mixtures here studied indicating the absence of polar behavior. Incidentally, it may be noted that there is evidence in the power factor measurements at high frequency on the oil, that the latter also has slight polar properties, evident, however, only above 50 kc.

The curious variation of power factor and conductivity with resin content is very suggestive as to the nature of the resin-oil mixture. It will be recalled that the variation of power factor with resin content, shown in Fig. 6, is also followed with close similarity in the conductivities measured at 0.001 sec., 1 min., and 40 min. after the application of voltage. These relations clearly indicate that the variations in power factor are due to the variations in conductivity. The irregular variations of the conductivity with the amount of resin, and also with temperature, further suggest variations in the particular ways in which the resin molecule adheres to that of the oil. Obviously no certain explanation as to what is going on can be offered. It may be said, however, that analysis of the conductivity relations from the standpoint of electrolytic theory indicates that the observed effects cannot be accounted for by this theory. More promising suggestions are that the charge carriers are of colloidal size which combine with neutral molecules in different conformations for different amounts of resin present. A further suggestion is that of a change in the surface conditions between a liquid and a brass electrode. A charge adsorbed by the electrodes may vary with the ionic concentration of the liquid. If both these phenomena should be present, a picture is possible which would account for the double maxima at high temperatures. Further study will be necessary before any more definite statement can be made.

Many measurements on liquids have indicated, and it is commonly stated, that a liquid dielectric does not show the

phenomenon of the residual charge. Studies of space charge in liquids [10, 11, 12] have long since indicated the presence of a small residual polarization after the discharge of the electronic polarization. This has been explained in terms of accumulated space charges near the two electrodes and there has been good evidence that these space charges, owing to their low mobility, probably consist of central ions surrounded by clouds of neutral molecules. In the resin mixtures here studied these phenomena occur in much greater magnitude than those heretofore noted. The suggestion that the resin is present in the mixtures in colloid form is in harmony with the picture of the mechanism of the space charge behavior.

CONCLUSIONS.

1. Mixtures of abietic acid (resin) and a typical insulating oil are exactly additive by volume.

2. The addition of resin to the oil in mixtures up to 20 per cent. by weight increases the dielectric loss and power factor.

3. The loss at 60 cycles and in the temperature range 30° to 115° C. in all cases is exactly accounted for by an increase in ionic conductivity.

4. The dielectric constants of the mixtures are exactly accounted for by a simple additive law based on the dielectric constants of the components and the proportions in which they are mixed. There is no anomalous dispersion of the dielectric constant in the range 60 cycles to 50 kc. and 30° C. to 100° C. The dielectric constant has a constant value over this frequency range. There is, however, a slight upward trend in the value of power factor with frequency, indicating dispersion and dipole resonance at some higher frequency.

5. The additive laws of volume and dielectric constant indicate the absence of chemical combination in the mixtures. However, the increase of conductivity and power factor with resin content is not uniform, passing through several maxima and minima whose positions and values appear to vary uniformly with temperature. The regularity of these variations seems to indicate a systematic change in the relation of the molecules of the resin and of the oil. Either a viscous emulsion or a colloidal suspension is suggested.

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NATURAL FREQUENCIES OF THREE PHASE WINDINGS.

BY

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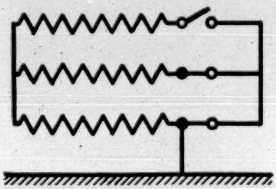
(*Concluded.*)

7. GROUNDED STAR-CONNECTED WINDING.

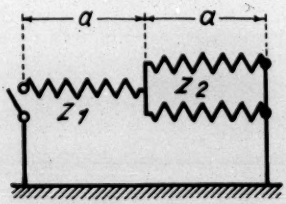
There remains now the investigation of the interruption of star-connected windings with ground fault, and we begin

FIG. 20.



Interruption of the first pole of a star-connected winding in grounded state, this pole belonging to the sound lines.

FIG. 21.

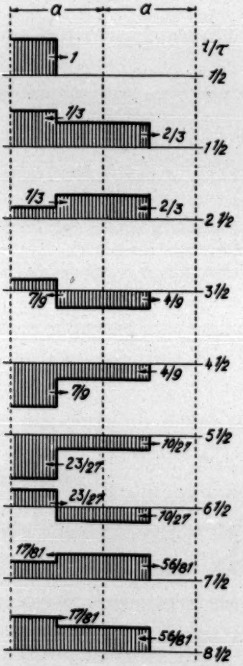


Straight-line diagram of the case of Fig. 20.

again with the opening of one of the sound phases, as in Fig. 20. The straight-line diagram for this case is shown in Fig. 21 and we see that this is similar to Fig. 6, only that the terminals of the paralleled phase windings are grounded and thereby act as short circuit points. Since the full interruption voltage appears at the open end of Fig. 21 and penetrates into the single winding, and since the laws of refraction at

the star point are well known, we can draw the successive courses of the waves as in Fig. 22. Up to 8.5τ no repetition of the original wave shape occurs, and even if we extend the picture we do not find an exact repetition. The nearest to

FIG. 22.



Development of interruption-voltage waves in the case of Figs. 20 and 21.

the original wave form occurs at about 6.5τ, but the agreement is only fair.

The absence of exact repetition means that the overtones of this distribution of voltage waves are not harmonic, and that the ratio of their frequencies to the fundamental fre-

quency is irrational. Although we see that the travelling time of the fundamental wave may be in the neighborhood of 6.5τ, apparently there is no possibility of deriving the exact value for its frequency, and the more for the frequencies of the overtones, by the simple method of determining the distance travelled until repetition of the initial wave form occurs.

Instead of using d'Alembert's method for considering the travelling waves which we have followed until now, we will apply Bernoulli's method, which consists in analyzing the phenomena by sine waves of various wave lengths. If we apply this method to the general case of two lines with different characteristics connected at one point, as in Fig. 23,

FIG. 23.

Two different lines joined at one end and forming an oscillating-system, the other ends being open and short-circuited respectively.

and open at one terminal while the other terminal is short circuited, we obtain from the balance of voltage and current at the junction point the solution for the natural frequencies ν

$$Z_2 \operatorname{tg}\left(\frac{\nu a_2}{v_2}\right) = Z_1 \operatorname{ctg}\left(\frac{\nu a_1}{v_1}\right), \tag{20}$$

where Z_1 is the surge impedance of the line with the open end and Z_2 that of the line with the short-circuited end. In the present case we have within the phase windings equal values of the wave velocity v and of the winding length a. Therefore equation (20) becomes

$$\operatorname{tg}^2\left(\frac{\nu a}{v}\right) = \frac{Z_1}{Z_2}, \tag{21}$$

which transforms easily into

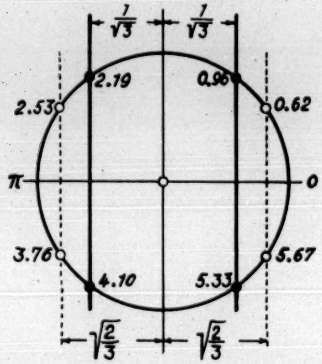
$$\cos\left(\frac{\nu a}{v}\right) = \pm \frac{1}{\sqrt{1 + Z_1/Z_2}} \tag{22}$$

For our diagram, Fig. 21, with $Z_2 = Z_1/2$, there is

$$\cos\left(\frac{\nu a}{v}\right) = \pm\frac{1}{\sqrt{3}}, \qquad (23)$$

which is represented graphically by Fig. 24. From this

FIG. 24.



Graphical representation of the roots of the characteristic equation determining the natural frequencies of two unequal lines, as shown in Fig. 23.

relation we obtain the roots

$$\nu\frac{a}{v} = \cos^{-1}\left(\pm\frac{1}{\sqrt{3}}\right) = 0.956; 2.186; 4.098; 5.328\cdots, \qquad (24)$$

and from them we derive the frequencies of the system

$$f_{\nu 1}' = \frac{\cos^{-1}(\pm 1/\sqrt{3})}{2\pi}\frac{v}{a}$$

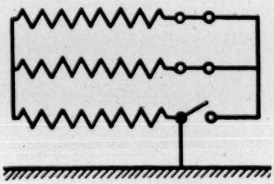
$$= \frac{v}{6.56a}; \frac{v}{2.86a}; \frac{v}{1.53a}; \frac{v}{1.18a}\cdots. \qquad (25)$$

By synthesis of oscillations with these frequencies the whole picture of Fig. 22 can be described. We see that the fundamental frequency is in the neighborhood of our estimated value and that the overtones are far from being

harmonic. The fundamental frequency is determined by an irrational number in contrast to the integer values which have been obtained in all the previous cases.

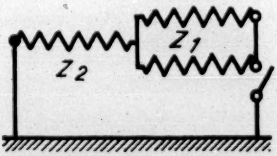
If the pole of the circuit breaker which is connected to the ground fault interrupts first, as in Fig. 25, the straight-line diagram is given by Fig. 26. Now the single winding has the

FIG. 25.



Interruption of the first pole of a star-connected winding in grounded state, this pole being adjacent to the ground connection.

FIG. 26.



Straight-line diagram of the case of Fig. 25.

short-circuited end and the paralleled windings have the open end, which is common to both. With regard to Fig. 23, here $Z_1 = Z_2/2$ and equation (22) becomes

$$\cos\left(\frac{\nu a}{v}\right) = \pm\sqrt{\frac{2}{3}}, \qquad (26)$$

which is represented by the dotted lines in Fig. 24. The solution is

$$\nu\frac{a}{v}\cos^{-1}(\pm\sqrt{2/3}) = 0.617;\ 2.527;\ 3.756;\ 5.668\cdots, \qquad (27)$$

and therefore the natural frequencies of this system are

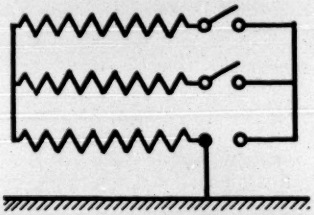
$$f_{\nu 1}'' = \frac{\cos^{-1}(\pm\sqrt{2/3})}{2\pi}\frac{v}{a}$$

$$= \frac{v}{10.2a}; \frac{v}{2.49a}; \frac{v}{1.67a}; \frac{v}{1.11a}\cdots. \quad (28)$$

Here also the overtones are not harmonic and the travelling distance of the fundamental oscillation is an irrational multiple of the length of the phase windings.

In both cases of grounded windings which we have just treated, the fundamental frequency is considerably lower than for insulated windings as given by equation (12).

FIG. 27.



Interruption of the last poles of a star-connected winding in grounded state, these poles belonging to the sound lines.

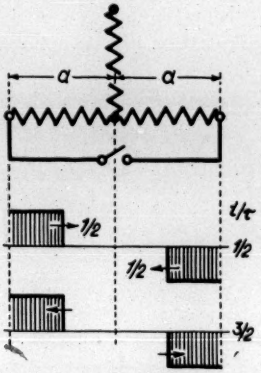
If finally, as in Fig. 27, we interrupt those poles which are connected with the lines originally sound, the voltage divides into halves, of value $\pm 1/2E$. The equivalent straight-line diagram is represented in Fig. 28 and we see that the grounded phase winding is only an attachment to the center point. Since this point always has voltage zero, according to the course of the travelling waves in Fig. 28 which is the same as that of Fig. 8 and Fig. 1, the third phase remains dead and has no influence whatsoever on the natural frequency. The value of the frequency is therefore

$$f_{\nu 2}'' = \frac{v}{4a}, \quad (29)$$

which is very different from the fundamental value of equation (28) valid for the pole opening first in this case.

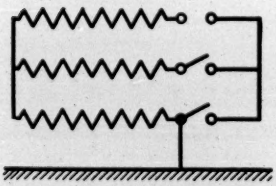
Finally there remains the case of Fig. 29 in which the grounded pole of the circuit breaker interrupts last. The

FIG. 28.



Voltage waves developed in the case of Fig. 27

FIG. 29.

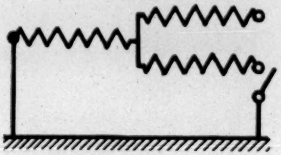


Interruption of the last poles of a star-connected winding in grounded state, these poles being adjacent to the ground connection.

straight-line diagram of Fig. 30 shows that this example is similar to that of Fig. 26, except that the two open ends on the right-hand side are not connected with each other. In consequence only one of the open phase windings is excited, the other one remaining without external voltage impulse. Instead of pursuing the fairly complicated distribution of the

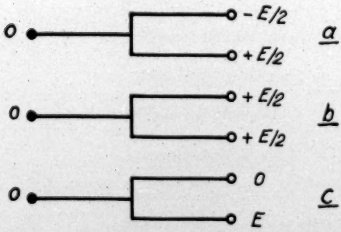
travelling waves in this system with three interlinked branches, we can assume it to be composed of two simpler distributions, as shown in Fig. 31. Fig. 31*a* represents the excitation of the two open branches with the voltages $\pm E/2$, the oscillations of this system being already indicated by Fig. 28 and equation (29). Fig. 31*b*, however, represents the excitation of both ends with equal voltages, $+E/2$, the oscillation for this case being indicated by Fig. 26 and equation (28).

FIG. 30.



Straight-line diagram of the case of Fig. 29.

FIG. 31.



Interruption-voltage in the case of Fig. 30 consisting of the superposition of two systems of voltage as shown in Figs. 26 and 28.

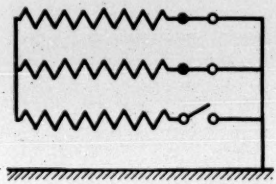
By addition of these two initial distributions of voltage we obtain Fig. 31*c* which coincides exactly with Fig. 30. We see from this superposition that this system responds with two different series of oscillations, both of the same magnitude. Their fundamental natural frequencies are

$$f_{\nu_2}' = \frac{v}{4a} \quad \text{and} \quad \frac{v}{10.2a}. \tag{30}$$

The total voltage of interruption therefore divides into two oscillations of equal amplitude but of very different frequencies. In this case we can not consider the faster oscillation as an overtone of the slower one, as both have the same importance for the interrupting process.

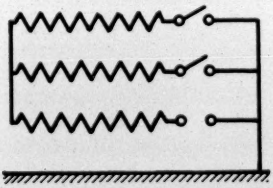
In all previous examples we have drawn the diagrams so that they contain a well-determined ground connection immediately adjacent to the poles of the star or of the delta

FIG. 32.



Interruption of the first pole of a star-connected winding in grounded state, the ground fault being situated on the external lines.

FIG. 33.



Interruption of the last poles of a star-connected winding in grounded state, the ground fault being situated on the external lines.

winding. For tests with circuit breakers in high-power laboratories these schemes are widely used. In practice, however, the connections may be slightly different. Frequently the circuit breaker is adjacent to the winding of the machine or transformer, and the ground fault is situated on the line, so that the diagrams of Figs. 32 and 33 are valid for the poles interrupting first and last. We realize, however, that these are by no means different examples from those

already discussed; rather they are merely different representations of Figs. 20 and 7. The same remark naturally holds true for delta windings also. Our investigations therefore have covered the entire field of possible connections in three-phase systems.

8. CONCLUSIONS AND COMPARISON WITH EXPERIMENTS.

In order to make easier the use of our formulae in practice, the various examples which we have discussed are condensed in Table I, with the exception of the trivial case of a neutral-grounded star system mentioned in section 2. We see that for insulated three-phase windings, which means the interruption of a mere short circuit, the natural frequencies are the same for the poles interrupted first and last in both star and delta connection. But the values for star connection are, of course, different from the values for delta connection. For grounded windings, however, which means the interruption of a combined short-circuit and ground-fault, we have a wide variation of natural frequencies for the pole interrupting first as well as for the pole interrupting last, both for star and delta connection. The only general rule we can derive here is that the natural frequencies in the grounded condition are always less than in the insulated state, the ratio varying up to 2 : 1 and 2.6 : 1.

As most circuit breakers are more sensitive in their interrupting and arc-extinguishing qualities with higher frequency of the restriking voltage, it appears advisable to test such breakers with an insulated system throughout and not with a grounded one. This has the additional advantage that there is but one single well-determined frequency for the poles interrupting either first or last, while with a grounded system widely different frequencies may be produced, depending on but slight differences in the ground connection and the sequence of interruption, which can never be predicted.

In Table I are given not only the fundamental frequencies but also the series of multiplication factors for calculating the higher harmonics. This arrangement of the table makes it useful for comparing our formulae with test results on the natural frequencies, measured with a three-phase, 50,000 kVA-turbo-generator for 22 kV, 3000 r.p.m. under various

TABLE I.

Natural Frequencies of Three-Phase Windings at Various Internal and External Conditions.

Winding:	Interruption:	Y	Δ
Insulated.	First Pole.	Fig. 4 $f = \frac{v}{4a}$ $\times$ 1, 3, 5, 7 $\cdots$	Fig. 9 $f = \frac{v}{3a}$ $\times$ 1, 2, 3, 4 $\cdots$
	Last Pole.	Fig. 7 $f = \frac{v}{4a}$ $\times$ 1, 3, 5, 7 $\cdots$	Fig. 12 $f = \frac{v}{3a}$ $\times$ 1, 2, 3, 4 $\cdots$
Grounded.	First Pole Insulated.	Fig. 20 $f = \frac{v}{6.56a}$ $\times$ 2.3; 4.3; 5.6 $\cdots$	Fig. 14 $f = \frac{v}{4a}$ $\times$ 1, 3, 5, 7 $\cdots$
	Last Pole Grounded.	Fig. 29 $f_1 = \frac{v}{4a}$ $f_2 = \frac{v}{10.2a}$	Fig. 16 $f = \frac{v}{6a}$ $\times$ 1, 2, 3, 4 $\cdots$
	First Pole Grounded.	Fig. 25 $f = \frac{v}{10.2a}$ $\times$ 4.1; 6.1; 9.2 $\cdots$	Fig. 18 $f = \frac{v}{6a}$ $\times$ 1, 2, 3, 4 $\cdots$
	Last Pole Insulated.	Fig. 27 $f = \frac{v}{4a}$ $\times$ 1, 3, 5, 7 $\cdots$	Fig. 19 $f = \frac{v}{3a}$ $\times$ 1, 2, 3, 4 $\cdots$

connections. The natural frequencies are determined not by interrupting short circuits but by a resonance method using an exterior source of high frequency, thus exciting every

possible frequency of the system under consideration without regard to the amplitude. We confine our comparison to the values measured for series connection of every phase winding for which extensive experimental results were obtained, although parallel connection of the halves of every phase was investigated also, and gave as good agreement.

As average of the tests on this generator there results a value of

$$\tau = 6.67\ \mu s \quad \text{or} \quad \frac{v}{a} = 150\ \text{kc/s}, \tag{31}$$

which we consider as a measured constant of the winding since we compare here only the influence of the schemes of connection. The wave velocity itself can be computed with a phase length $a = 250$ m as

$$v = 150 \cdot 10^{-3} \times 250 = 37.5\ \text{m}/\mu s. \tag{32}$$

In Table II, which has the same arrangement as Table I, every measured natural frequency [1] is entered so that we can compare it easily with the calculated figures according to our formulae, including the harmonics, which are entered in the same squares. The agreement, particularly for the fundamental frequencies, which are the most important ones, is exceedingly good. Undoubtedly this agreement gives evidence that even in complicated systems like those under consideration, a primitive and natural approach to the problem gives results which may be more significant than those obtained by a highly intensified mathematical analysis.

To be sure, some higher harmonics do not show full agreement, presumably on account of a slight mutual capacitive influence between the end turns of the different phases of the machine, which we have intentionally neglected, and to which the higher harmonics are sensitive. We see that the measured frequencies of the higher harmonics are slightly less than the calculated ones, which should be expected from the influence of the internal coil and turn capacitances.

The excellent agreement between measurement and calculation with so many different connections of the windings

[1] The measurements have been made by Mr. J. S. Cliff at the Witton factories of The General Electric Co., Ltd., London.

TABLE II.

Comparison of Measured and Calculated Natural Frequencies of a Three-Phase Alternator. Frequencies in *kc/s.*

Winding:	Interruption:	Y Measured: Calculated:	Δ Measured: Calculated:
Insulated.	First Pole.	37.5 97, 146 37.5 113, 188	52 98, 130 50 100, 150
	Last Pole.	37.5 100, 152 37.5 113, 188	52 98, 130 50 100, 150
Grounded.	First Pole Insulated.	24 55, 72, 97, 135 23 52, 98, 127	37.5 92, 152 37.5 113, 188
	Last Pole Grounded.	15, 37, 72, 84, 97, 142 14.7, 37.5 60, 90, 113, 135	25 37.5, 52, 95 130, 150, 178 25 50, 75, 100 125, 150, 175
	First Pole Grounded.	14.3 52, 84, 98, 125 14.7 60, 90, 135	24.5 86, 175 25 50, 75
	Last Pole Insulated.	36.5 99, 144 37.5 113, 188	50 98, 125 50 100, 150

proves that the performance of machine windings corresponds under all circumstances with the formulae and the wave pictures which we have derived.

For transformers there exist measurements of the natural frequencies for star and delta connections, published in *Brown-Boveri Review*, 1937, p. 298, though the experiments are not so extensive and detailed as here. The tests concern mainly circuit interruptions with ground connection without, however, giving the exact location of the ground. The measurements of the natural frequencies are condensed in Table III, so far as they refer to comparable star and delta

TABLE III.

Comparison of Natural Frequencies of Three-Phase Transformer Windings in Star and in Delta Connection.

Frequency in *kc/s*.

Y-Connection	Δ-Connection	Ratio
22.2	36.4	1.64
25.2	40.0	1.59
22.4	36.9	1.65
44.0	66.8	1.52
49.6	73.3	1.48
44.0	66.9	1.52
22.7	35.4	1.56
25.2	38.9	1.54
24.6	36.2	1.53
42.6	67.0	1.57
48.0	72.0	1.50
43.0	67.2	1.56
32.0	49.0	1.53
33.2	49.0	1.48
32.0	49.2	1.54

connections of the same transformer winding. We see that the ratio of the tabulated frequencies covers only the narrow range from 1.48 to 1.65. According to our calculations and Table I, the ratio should be either $4/3 = 1.33$, or $6.56/4 = 1.64$, or $10.2/6 = 1.70$, depending upon the detailed conditions of the case under consideration.

This agreement is satisfactory and proves that the results of our investigations can be used for transformer windings also.

9. SUMMARY.

The frequencies of natural oscillations formed in three-phase windings of electric power circuits vary over a wide

range, depending on the internal and external connections of the circuits. Star and delta connection of the winding, insulated and grounded condition of the system, and the influence of the first and the last interrupting pole in three-phase circuit breakers are analysed in their influence on the natural frequencies excited in such multiple-coupled systems. The results of many tests on actual machines show excellent agreement with the calculated results.

Since the natural frequencies of insulated circuits are found always to be higher than those of grounded systems and, in addition, are independent of the random character of the sequence of interruption of the three poles of a circuit breaker, it is expedient to base tests of the interrupting capacity of three-phase circuit breakers exclusively on ungrounded systems.

U. S. D. A. Scientists Make Sugar From Sorgo Plant.—By discovering means of removing starch and aconitic acid from the juice of the sorgo plant, used extensively in this country for making the ordinary sorghum sirup, scientists of the United States Department of Agriculture have developed a method for obtaining a satisfactory yield of sugar crystals which may be made into refined or granulated sugar by the customary procedure. One step of the new process closely parallels a chemical change that occurs in the human digestive process. In making the announcement the Department pointed out that sorgo sugar has been produced only on a semi-industrial scale and that studies now must be conducted by the Bureau of Plant Industry, which is handling the agronomic phases of this project, to find what varieties of sorgo are best suited for sugar production and where it can be most profitably grown. Research on the present project was begun only two years ago at Meridian, Mississippi, by EMIL K. VENTRE and S. BYALL under the direction of H. S. PAINE. Many previous attempts had been made by Department chemists to recover sugar from sorgo juice by a commercially feasible method but all failed. The project was reopened when the investigators found that certain sorgo varieties used for sirup production gave juices of high sugar content comparable to some standard sugar cane varieties. Studies directed toward starch removal have resulted in simple methods that worked successfully on pilot plant scale. The cane is double-milled and the raw juice is then centrifuged removing from 3 to 10 pounds of starch per ton of cane. The centrifuged juice is then treated with lime, heated, and allowed to settle in a conical tank. The clear juice at the bottom is drawn off and the scum on the top is forced through a filter press to recover the juice it contains. This leaves a small amount of starch in the juice which must be removed, otherwise the sirup would jell instead of crystallize. Here the investigators took a tip from the human digestive system. Certain enzymes in the digestive tract change starches to sugar. By treating the juice at this stage with an enzyme, pancreatic amylase, in a very small amount, the remaining starch is converted to products which do not seriously interfere with crystallization of sugar.

R. H. O.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

RADIATION FROM FLUORESCENT LAMPS.

The new fluorescent lamps, now coming into extensive use, are made up of a glass tube lined with a thin film of a substance that is excited to fluorescence by the ultraviolet rays emitted when an electric discharge is passed through mercury vapor within the tube.

If the lamp were made of clear quartz or of certain kinds of glass, the radiation from the electric arc discharge through mercury vapor, being very strong in the spectral region 2,537A to 2,804A, might cause conjunctivitis, and would have a highly germicidal effect.

In response to repeated inquiries concerning the ultraviolet emission from these lamps, the Radiometry Section of the Bureau has examined several makes and colors, including daylight (white), red, gold, green, blue, and pink, as well as a lamp having one half of the tube lined with blue fluorescent material while the other half was of clear glass. The lamps were all of the 115-volt, 15-watt type.

It was found that all the tubes were made of a kind of glass that is highly opaque to short ultraviolet wave-lengths; moreover, the fluorescent lining (especially in the red, gold, and pink colored lamps) increased the opacity of the glass to ultraviolet radiation of wave-lengths shorter than about 3,000A.

The shortest observable wave-length emitted by any of the lamps was found to be the mercury line at 3,132A. This emission line was weak in the daylight, green, blue, and pink lamps, and in the clear tube, and was not observed at all in the red and in the gold-colored lamps. The ultraviolet emission line of mercury at 3,663A was present, but weak, in all the lamps except the gold one. These ultraviolet emission lines are of wave-lengths that occur in sunlight, and appear to be harmless in the fluorescent lamps, as used.

* Communicated by the Director.

By means of a tantalum photoelectric cell, having a maximum sensitivity at 2,537A, check measurements were made against a "cold quartz" mercury arc, which is regularly used as a standard of germicidal ultraviolet radiation. In comparison with the standard lamp, it was estimated that, to 1 part in 50,000, no radiation of wave-length 2,537A could be detected at a distance of 10 cm. (4 inches) from the fluorescent lamps.

From these observations it appears that no ultraviolet radiation of wave-lengths shorter than 3,000A (not in sunlight) emanates in appreciable amounts from fluorescent lamps as used for illumination.

DISTRIBUTION OF OZONE IN THE STRATOSPHERE.

Measurements of ultraviolet solar radiation intensities in the stratosphere, made during 1937 and '38, were reported by W. W. Coblentz and R. Stair in *J. Research NBS*, **22**, 573 (1939); RP1207. A paper by the same authors describing similar measurements during the summers of 1939 and '40, using improved apparatus, will appear as RP1367 in the *Journal of Research* for February.

The apparatus that was transported aloft by unmanned balloons consisted of the following elements: (1) A photoelectric cell and filter radiometer, connected with a balanced amplifier, relaxation oscillator, and radio transmitter for measuring the ultraviolet intensities; (2) a radio-operated barometer, giving the heights attained by the apparatus; and (3) an electrolytic resistor for measureing the ambient temperature of the ultraviolet intensity meter.

The audio-frequency modulated radio wave, giving (1) the intensity of the incident ultraviolet solar radiation, (2) the elevation of the apparatus, and (3) the temperature of the ultraviolet meter, was received and graphically recorded at a fixed ground station (*J. Research NBS*, **20**, 185 (1938); RP1075).

In three successful flights made in June, 1939, and in two similar flights in 1940, the ultraviolet radiometer attained heights ranging from about 78,000 to about 88,000 feet (23 to 27 km.). From the observed change in filter transmissions

of ultraviolet solar radiation with elevation, it is deduced that the apparatus passed through 65 to 70 per cent. of the ozone, and other ultraviolet-absorbing constituents, if any, in the upper atmosphere, most of which are localized in a layer extending from 15 to 27 km., with a wide maximum of concentration at a height of about 24 to 25 km., above the earth's surface. At the highest elevation attained by the instruments, the intensity of the ultraviolet solar radiation of wavelengths shorter than 3132A was 10 to 12 times that observed at sea level.

RAPID METHOD FOR DETERMINING ASCORBIC ACID CONCENTRATION.

In the course of investigations at the Bureau for the Florida Citrus Commission on the effect of citrus fruits upon the human organism, it was found necessary to develop a method of determining the vitamin C content of the blood of a large number of individuals in a short time. As described in RP1364 by M. A. Elliott, A. L. Sklar, and S. F. Acree in the *Journal of Research* for February, blood samples from 140 men were regularly used in this work. Seventy of these were being fed one and one-half grapefruits per day and had high ascorbic acid concentrations in the blood, while the remaining seventy were on the same diet, except for the lack of citrus fruit, and had a low ascorbic acid concentration. The plasma is not deproteinized, but is diluted with 5 per cent. acetic acid and used directly in a specially constructed photoelectric comparator with the dye 2,6-dichlorophenolindophenol. The ascorbic acid content of the plasma sample is read directly from empirical calibration curves determined by adding known amounts of ascorbic acid to blood plasma. The comparator is operated so as to compensate automatically for the usual variation in the turbidity and color of plasma samples. While the method is quite rapid once it is in operation, some time must be spent in preparing calibration curves. The maximum total error in the determination on plasma samples containing from 0 to 3.5 mg of reduced ascorbic acid per 100 ml of plasma was estimated to be ± 0.1 mg/100 ml.

MICROSCOPIC STRUCTURE OF THE COTTON FIBER.

A knowledge of the structure of the cotton fiber must be the basis of any intelligent application of the many processes which the fiber may have to undergo in the manufacture of yarns and fabrics. Accordingly, any new information concerning the structure of the fiber may have important practical results.

The cell of the cotton fiber has a primary and a secondary wall. The primary wall is considered to be the outer sheath of the fiber, or the portion of the wall formed as the fiber increases in length. Secondary wall refers to that part of the wall which is laid down after the fibers cease to elongate appreciably. Only the thin primary wall encloses the protoplasm of the cotton fiber during the first 15 to 20 days after its origin. Thereafter, the thickness of the wall is increased by a deposition of cellulose which comprises the secondary wall.

The present investigation, conducted by Charles W. Hock, Robert C. Ramsay, and Milton Harris, research associates of the Textile Foundation at the Bureau, is concerned with the structure of the cotton fiber as observed after various purifying and swelling treatments. The fibers were examined in ordinary and in polarized light. In carrying out microscopic investigations of this sort, the question often arises whether the structures which are seen are real. For example, are the apparent fibrils which may be observed under various conditions of illumination, real structures or are they merely the result of surface irregularities or diffraction phenomena? To aid in answering such questions, a micromanipulator can be of great help. This instrument makes possible the precise mechanical control of fine glass needles (about 0.0001 inch wide at the tip) whereby fibers can be dissected, flattened, stretched, and otherwise handled so as to calrify their details.

As explained in RP1362 in the February *Journal of Research*, the wall of a mature cotton fiber appears to have the following structure. The secondary wall, which comprises the bulk of the fiber, consists of innumerable spirally oriented cellulose fibrils enclosed by a widing which also makes a steep spiral, but in the opposite direction from the former. The winding and the fibrils reverse their direction at frequent

intervals, their points of reversal being coincident. The secondary wall is enclosed by a thin primary wall which covers the former like a sausage casing. The primary wall is made up of fine criss-crossing strands of cellulose embedded in a membrane consisting principally of wax and pectic substance. The lumen, or central cavity also contains wax and pectic materials, plus various amounts of degenerated protoplasm.

When cotton fibers are swollen under certain conditions a layered structure is discernible in the secondary wall. As seen in cross-sections the wall appears to be made up of concentric cylinders of cellulose. The number of these cylinders increases with the age of the fiber.

In certain reagents, such as cuprammonium hydroxide and trimethylbenzylammonium hydroxide, the fibers often swell irregularly along the axis, and thereby give rise to socalled "balloons." When many balloons are formed in a single fiber the latter has an appearance resembling a string of beads. The formation of these structures upon swelling appears to be dependent in part on the orientation of the fibrils, and in part on the constricting influences of the outer winding and of the primary wall.

BASIC SHEET SIZES FOR PAPER.

Simplified Practice Recommendation R22–40, Paper, the second revision of this recommendation, establishes basic sheet sizes for bond and writing papers, rag content and sulphite; ledgers, rag content and sulphite; loose-leaf ledgers, rag content and sulphite; machine-posting ledgers, rag content; book paper, uncoated, coated two sides, coated one side, and offset; index bristol; and cover paper.

This revision represents the results of studies of current requirements in the paper consuming trades, made by the Book Paper Manufacturers Association and the Writing Paper Manufacturers Association, and differs from the previous edition in that the broad classes of paper have been subdivided in those cases where the sizes of papers of different substance or finish are not the same throughout the class. In addition, the scope of the program has been enlarged to cover loose-leaf and machine-posting ledger papers.

The simplification of sizes of basic paper sheets started with the appointment in 1921 of seven committees of the paper industry to make studies of the various phases of paper standardization. From the information thus obtained, a simplified list of paper sizes was drafted in 1923 by a general conference of manufacturers, distributors, and users of paper, and in 1924 this list was promulgated as Simplified Practic Recommendation R22. The standing committee in charge reaffirmed the recommendation without change in 1927 and 1929, and revised it for the first time in 1933. The present revision, which became effective on December 31, 1940, was approved by the standing committee, whose members represent firms and associations concerned with the manufacture and distribution of paper, and publishing, advertising, purchasing, printing, and allied interests.

The complete publication will contain, in addition to the simplified schedule of sizes and varieties of paper, a brief history of the project, and lists the members of the standing committee and acceptors of the recommendation. Until the printed issue is available, free mimeographed copies may be obtained from the Division of Simplified Practice, National Bureau of Standards, Washington, D. C.

CORROSION PITTING OF ALUMINUM BRONZE AND MONEL METAL IN WATER.

The influence of stress on the corrosion pitting of aluminum bronze and monel metal under water has been investigated by D. J. McAdam, Jr. and Glenn W. Geil. This work is described in the February *Journal of Research* (RP1365).

Corrosion pits in steel are free to assume a roughly hemispherical form. This is also true of monel metal, but is not the case with aluminum bronze, because the pits are confined between crystallites of the alpha phase. Pits in aluminum bronze and monel metal are much smaller than those in steel, but cyclic stress tends to increase both their size and sharpness, a sufficiently high combination of stress, cycle frequency, and corrosion time causing fissures to develop from blunt pits. Fissures in aluminum bronze generally are ob-

lique, whereas those in steel and monel metal tend to be perpendicular to the direction of the principal tensile stress.

The effective stress concentration that causes the lowering of the fatigue limit depends on the size and sharpness of the pits. The curves of decrease of the fatigue limit with corrosion time are of the "accelerated damage" type, and are obtained when the corrosion rate is anodically controlled. With these two alloys, therefore, the pits in a specimen have a wider range of size and sharpness than the pits formed under cathodic control, as in steel. The pit that caused the lowering of the fatigue limit sometimes is much larger and sharper than the pits found in the sectional views, and for this reason, the damage may be greater than the sectional views would indicate. Many of these views, however, give good correlation with the resultant fatigue limits.

Steady stress tends to accelerate corrosion of aluminum bronze, but steady stress of any attainable value has no apparent effect on the corrosion pitting of monel metal.

THE FRANKLIN INSTITUTE.

STATED MONTHLY MEETING, FEBRUARY 19, 1941.

The stated monthly meeting for February was held on the evening of Wednesday, February nineteenth, at eight-fifteen o'clock. Mr. W. Chattin Wetherill, Vice-President, presided.

The minutes of the previous meeting were approved as printed in the February issue of the Journal.

The Presiding Officer called upon the Secretary, Dr. Henry Butler Allen, for a report.

The Secretary reported that since the last meeting of the Institute the following additions had been made to the membership:

Active	7
Associate	14
Student	40
	61

He then proposed for Honorary Membership in The Franklin Institute, upon recommendation of the Board of Managers, the two Franklin Medalists for the year 1941, namely:

Dr. Edwin H. Armstrong,
Columbia University,
New York City

and

Sir Chandrasekhara Venkata Raman,
Indian Institute of Science,
Bangalore, Mysore, India.

Upon motion, duly seconded, these gentlemen were declared elected.

There being no further business, Mr. Wetherill introduced the speaker of the evening, Dr. H. A. Toulmin, Jr., Attorney-at-law, Dayton, Ohio. He reviewed Dr. Toulmin's brilliant record in the World War I, where he was Chief of the Coördination Staff of the United States Army Air Corps in France. For his work he was honored with the Distinguished Service Medal. At present he is a Colonel in the Infantry Reserves.

Dr. Toulmin then spoke on "Reminiscences and Reforms of the Patent Law" and related many amusing experiences in his long career as a patent attorney. He also spoke at length regarding the needed reforms in the patent law and recited some of his own efforts to bring about such reforms. His enlightening talk brought forth many questions from the audience.

After the discussion the meeting was dismissed with a vote of thanks to the lecturer.

HENRY BUTLER ALLEN,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, February 12, 1941.)

HALL OF THE COMMITTEE,
PHILADELPHIA, FEBRUARY 12, 1941.

MR. COLEMAN SELLERS, 3RD, *in the Chair.*

The following report was presented for final action:

No. 3090: Clark Medal.

This report recommended the award of a Walton Clark Medal to Raymond Mower Conner, of Cleveland, Ohio, "In consideration of his outstanding service to the Gas Industry as organizer and director of the work of the American Gas Association Testing Laboratories, which has resulted in important developments in performance, durability and safety of gas appliances and in fundamental research work of great value."

JOHN FRAZER,
Secretary to Committee.

LIBRARY NOTES.

Photostat Service. Photostat prints of any material in the collections can be supplied on request. Orders received in the morning are filled the same day. The average cost for a print 8½ × 11 inches is forty cents.

The library and reading room are open on Mondays, Tuesdays, Fridays and Saturdays from nine o'clock A.M. until five o'clock P.M., Wednesdays and Thursdays two until ten o'clock P.M.

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NOTES FROM THE BARTOL RESEARCH FOUNDATION.

USE OF A GRID TO REDUCE OPERATING VOLTAGE IN GEIGER-MUELLER COUNTERS.*

BY

S. A. KORFF† and W. E. RAMSEY.

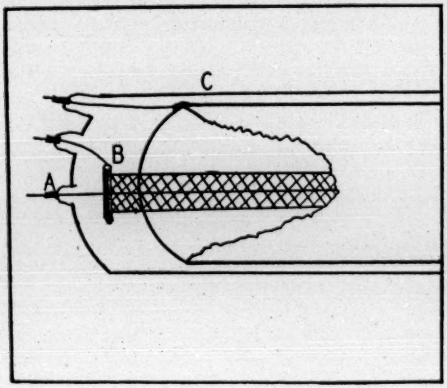
It is well known that the bulk of the multiplicative ionization in the discharge of a counter takes place in the immediate vicinity of the central wire. The rest of the counter acts principally as an ion-collecting volume. To obtain an adequate field in the neighborhood of the wire of a large counter, it is necessary to apply a high potential to the outer cylinder. It is obvious that a much lower field would suffice in the outer part of the counter, to accelerate the ions in towards the central wire, provided that a high field can be maintained near the latter to provide the accelerating region for counter action.

The counter shown in Fig. 1 exhibited the following characteristics: (*A*) The outer cylinder was made positive with respect to the grid. A potential was applied to the grid, making it negative with respect to the central wire, and increased until counting action took place. The operation was then equivalent to that of a counter of the dimensions of the grid alone. The counting rate, as a function of grid-voltage, is given in Table I. The same counting rate was obtained for all cylinder-to-grid voltages between five and 200. It is obvious that in this case no ions formed in the volume between the grid and the cylinder would pass through the grid and enter the accelerating region near the wire, since the potential reversed at the grid. (*B*) When the grid was electrically connected to the cylinder, or at a potential within five volts (either sign) thereof, a sufficiently field-free space is

* Condensed from an article published in full in *The Review of Scientific Instruments*, **8**, 267 (1940).

† Research associate, Carnegie Institution of Washington.

FIG. 1.



Counter with grid around central wire. Cylinder *C* is partly cut away to show grid *B* surrounding central wire *A*. Entire assembly is mounted in a glass envelope filled with 1 cm. Argon and 0.5 cm. BF_3.

TABLE I.

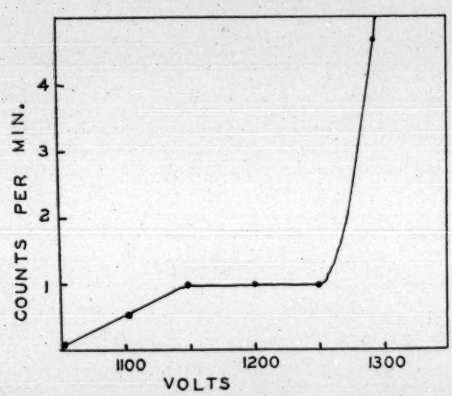
Counting Rate of Counter for Various Voltages Between Wire and Grid when Cylinder is (1) More Negative, and (2) More Positive than Grid. The Ratio of the Counting Rates Under these Two Conditions is Roughly Equal to the Ratio (5.6) of the Cross-sectional Areas of the Cylinder and Grid. Counter Exposed to Cosmic Radiation Plus Normal Local Radioactivity Only.

Voltage Between Wire and Grid.	1260	1380	1490
Counting rates:	Starting potential for beta- and gamma-ray counting		
1. Cylinder more negative than grid		114	210 per min.1
2. Cylinder more positive than grid		23	38
Ratio of 1 to 2		4.96	5.51

formed between the two electrodes. In this case, the counter was observed to break down into a continuous discharge as soon as the voltage of the grid was raised to the starting potential. This was due to a continuous supply of ions

drifting in from the field-free space, each initiating a new discharge. (*C*) When the potential of the cylinder was made 10 to 200 volts more negative than the grid, the counter behaved essentially as if its volume were that of the cylinder. The counting rate for the case of the cylinder negative is also shown in Table I. It will be seen that this is roughly 5.5 times that when the cylinder was positive. This ratio is roughly that of the cylindrical surface areas, and hence what

FIG. 2.



Subthreshold counting rate of counter described, when in the presence of slow neutrons. Beta-rays are counted at voltages above 1250. The large plateau is produced by the alpha-particles from the B^{10} (n, α) reaction. This behavior is similar to that of counters without the grid; but the plateau will occur at higher voltages.

one would expect for such an arrangement exposed to cosmic radiation.

The most important property of this arrangement is that the counter in question actually operated at around 1300 volts grid-to-wire potential, plus, say 50 volts between grid and cylinder, whereas a counter of the dimensions of the cylinder alone necessitated around 1800 volts. This reduction in operating voltage recommends such a counter for balloon experiments. Here the weight of a high potential source is a serious limitation.

It was desired to ascertain whether this counter would operate as a proportional counter for detecting neutrons. A source of Rn-Be neutrons was placed in a bucket of water next to the counter, and the sub-threshold counting rate was plotted as a function of voltage. The resulting curve, Fig. 2, shows the usual alpha-particle-plateau characteristic of such counters and indicates that this counter may be employed for this purpose. It might be expected that the efficiencies when (*a*) the cylinder is positive with respect to the grid, and that when (*b*) it is negative, would stand in the same ratio as the volumes (*a*) of the grid and (*b*) of the cylinder. However, experiment shows that, in the counter described above, the ratio is less than might be expected.

NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION.

Annual Biochemical Research Lecture. DR. HENRIK DAM, Associate Professor of Biochemistry at the University of Copenhagen, delivered the Annual Biochemical Research Lecture at the University of Delaware on January 8th on "The Present State of Knowledge of Vitamin K." He also visited the new laboratory building of the Biochemical Research Foundation in Newark, Delaware, during the afternoon and conducted a seminar on "Factors in Preventing the Escape of Blood from the Vascular System."

During an investigation on the sterol metabolism of chicks, in 1929 and 1930, Dr. Dam discovered that chicks fed on diets which contained no sterols and low quantities of lipoids frequently developed extensive hemorrhages in those parts of the body subject to trauma, such as the wings, breast and legs. Later he found that this dietary hemorrhagic disease was not affected by vitamins A, B_1, B_2, C, D and E or any known constituent of the diet, and concluded that preventive diets contained an antihemorrhagic factor with the characteristics of a vitamin. He suggested the term vitamin K for this antihemorrhagic factor.

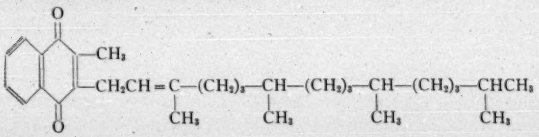
It has been found that vitamin K occurs in two forms in nature: vitamin K_1 produced in green leaves, and vitamin K_2 produced by bacteria such as *Es. coli* which appear in the intestinal tract. Chicks have proved to be the most satisfactory animals for testing for vitamin K as they develop the hemorrhagic disease fairly rapidly, within 14 to 28 days when kept in carefully cleaned cages to eliminate access to fecal matter. Mammals have been shown to develop the disease much more slowly probably due to the longer large intestine which permits the formation of more of the vitamin. Without the intestinal bacteria man would have to eat approximately two pounds of spinach a day to acquire the necessary amount of the vitamin, if the requirement per g. body weight is the same as for the chick.

The determination of vitamin K has been carried out in Dr. Dam's laboratory by means of a curative blood-clotting method. The blood is collected, in paraffined tubes, from the carotid artery of the chick, the plasma diluted with an equal amount of Ringer solution, and the clotting time determined by mixing 4 drops of plasma (0.2 cc.) with one drop of chicken muscle extract (0.05 cc.) in a micro test tube. By using a series of different concentrations of the tissue extract, it is possible to find the concentration (K) which produces clotting in 3 minutes. If the concentration of extract which clots normal plasma in 3 minutes is K_n, the equation, $\frac{100 \times K_n}{K}$ = amount of prothrombin, will characterize the degree of reduction of the clotting power. The prothrombin-values are determined on a series of K-avitaminous chicks, vitamin K is given for 3 successive days, and the prothrombin-values again determined on the 4th day. A new preparation is compared with a standard preparation of vitamin K and the unit defined as that quantity of vitamin which must be given per gram body weight of chick during 3 days in order to bring the prothrombin value from a low level to the normal level.

Green leaves of all varieties are a fairly rich source of vitamin K. Fruits, except tomatoes, are quite low in the vitamin, cereals very poor, while carrots and potatoes contain practically none. Vitamin K is synthesized in the sunlight in plants and in the plant cell it is associated with the chlorophyll. Animals apparently are not able to store much vitamin K as most animal tissues and milk contain very little. The richest animal source is hog liver. Certain bacteria are also rich sources.

Vitamin K_1 appeared in the fat-soluble, nonsterol fraction of the extract from alfalfa. It was inactivated by saponification, light and bromine. Physical methods, such as chromatographic adsorption, freezing and molecular distillation, were used for concentration of the vitamin. The pure substance was finally obtained as a pale yellow oil which crystallizes at low temperatures and melts below 0° C. Vitamin K_2 (prepared by Doisy and coworkers) melts at 54° C., contains more double bonds and possesses slightly lower activity than vitamin K_1. The characteristic absorption spectrum is prac-

tically the same for the two substances. Vitamin K_1 has been shown (Doisy and coworkers and Fieser and coworkers) to be 2-methyl-3-phytyl-1,4-naphthoquinone:



while vitamin K_2 has the same structure with a different side chain. Vitamin K_1 has been synthesized and various other 1,4-naphthoquinone derivatives have been shown to possess vitamin K activity. Certain benzoquinones and anthraquinones have also been shown to have some activity. The synthetic products have now been adopted for clinical use due to the difficulty and expense of obtaining the natural vitamins. Water soluble derivatives have also been prepared which have proved to be important for intravenous vitamin K therapy.

According to the classical theory of blood coagulation the following substances take part in the process:

$$\text{Prothrombin} + \text{thrombokinase} + Ca^{++} \rightarrow \text{thrombin}$$
$$\text{Fibrinogen} + \text{thrombin} \rightarrow \text{fibrin}.$$

The hemorrhagic tendency in K-avitaminosis is due to a marked decrease in the prothrombin concentration of the blood; the other constituents remain unchanged. Vitamin K, added to blood in vitro, has no coagulant action and, after intravenous injection into animals with a low prothrombin level, approximately 5 hours elapse before the prothrombin content of the blood has reached values between 50 and 100% of the normal value. It thus appears that vitamin K exerts its action on the cells of the body causing them to produce prothrombin. Considerable evidence exists which indicates that the liver is an important organ for the production of prothrombin. Vitamin K is probably not a part of the prothrombin molecule since the artificial vitamin K-active substances do not produce prothrombins which react differently from normal prothrombin. The mechanism of the action of

vitamin K in prothrombin synthesis is as yet unknown. The vitamin disappears rapidly from the body but the means of disposal is still to be investigated. There is apparently no danger in giving large doses of vitamin K as the amount of prothrombin cannot be raised much above the normal level even with excessively large doses.

Vitamin K therapy is being used successfully in hemorrhagic diseases which are the result of a low prothrombin concentration in the blood. Since vitamin K is a fat-soluble material, bile is necessary for its absorption from the intestinal tract. The water-soluble naphthoquinone derivatives can be given orally without bile acids. Patients with obstructive jaundice are now treated with vitamin K and bile salts before and for two weeks after an operation. Treatment after the operation is necessary since the production of bile salts by the liver is low after jaundice and the food intake is also low. This treatment has eliminated post-operative hemorrhage in such cases. Hypoprothrombinemia in new-born infants occurs regularly during the first week after birth. The minimum of prothrombin occurs three days after birth due to the lack of vitamin K in the food and the low bacterial content of the intestinal tract. After the third day the prothrombin concentration of the blood starts to rise. A prothrombin level which is 20% of normal is a critical level for hemorrhage. One-third to one-quarter of new-born babies have prothrombin levels in this range while one percent show actual hemorrhage. Mothers, as a rule, show an increased prothrombin concentration at the termination of pregnancy. There are several possibilities for the low prothrombin level in the infant: (1) the placenta may not permit free passage of vitamin K, (2) the mother may need and use large amounts of vitamin K so there is not enough for the foetus, and (3) the foetus and newborn infant may need high amounts of vitamin K. Considerable success has been attained in the prevention of hemorrhage in new-born infants by treating both the mother and the baby with vitamin K. An intramuscular or intravenous injection of 5 to 10 mg. of vitamin K in the infant raises the prothrombin to approximately normal levels within 24 hours. Intracranial hemorrhage in the new-born is due to trauma and low prothrombin but vitamin K therapy for the mother before de-

livery is a help in preventing dangerous hemorrhages. Vitamin K therapy is also of advantage in sprue where the hypoprothrombinemia is caused by faulty absorption of fats from the intestine.

Hemorrhagic diseases which are not the result of a low prothrombin concentration in the blood, such as hemophilia and thrombocytopenia, are not benefited by treatment with Vitamin K.

(Reported by MURIEL PLATT MUNRO.)